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Soil variation and sampling intensity under **RED PINE & ASPEN** in minnesota

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CONTENTS

Study Areas	1
Results and Discussion	1
Summary and Conclusions	4
Literature Cited	4
Appendix	5

The author is a Soil Scientist for the Station and is headquartered at its Northern Conifers Laboratory in Grand Rapids, Minnesota. The Laboratory is maintained in cooperation with the University of Minnesota.

SOIL VARIATION AND SAMPLING INTENSITY UNDER RED PINE AND ASPEN IN MINNESOTA

David H. Alban

Many soil properties are extremely variable, even within small areas. Knowing the amount of this variation is necessary for accurate soil characterization and for better planning of studies to evaluate effects of land management on soils.

Agricultural soil variability has been studied to a limited extent, but little is known about variability of forest soils, and no data have been published on proper sampling intensity in northern Lake States forest soils. Some information on red pine (*Pinus resinosa* Ait.) plantation soil variability in the northeastern United States has been published (Mader 1963), but no such data are available for aspen (*Populus tremuloides* Michx.).

The main objective of this paper is to describe spatial soil variation so that the proper number of samples to collect can be determined. In addition, some information is presented on seasonal variation and laboratory analysis variation.

STUDY AREAS

Three red pine and three trembling aspen stands in northern Minnesota were sampled in July 1972. The red pine stands ranged in age from 49 to 72 years and the aspen 22 to 44 years. All stands were fully stocked (basal area = 90 to 200 ft²/acre). The presence of charcoal in the forest floor of all stands but the lack of tree fire scars or scorched bark indicated past fires but no recent ones.

All stands are on level to gently sloping land with relatively uniform surface topography, typical of red pine and aspen sites in Minnesota. The soils developed from glacial till or outwash sands and include Chisholm, Hiwood, Faunce, Menahga, and Zimmerman soil series. The surface soil textures are loamy sand to sandy loam, and are generally finer in aspen than in red pine stands.

More detail about the soils and tree stands on the study areas are presented in the Appendix (table 2). The methods of field sampling and laboratory analysis are detailed in the Appendix, page 5.

RESULTS AND DISCUSSION

Soil Properties on Study Plots

The soils studied exhibit a wide range in some properties but a limited range in others (Appendix, table 2). For example, mineral soil pH and bulk density do not differ greatly from plot to plot, whereas many other properties commonly differ by a factor of three or more from one plot to another. Most soil properties are similar in both red pine and aspen stands, especially in the Hiwood soil series which supports both types. The greatest differences between species are in Ca and Mg content, both of which are higher under aspen in the forest floor and in two cases much higher in the 10 to 40 inch layer.

Most red pine and aspen stands we have examined in Minnesota occur on soils with characteristics which fall within the ranges reported in the Appendix, table 2. Therefore the number of samples to collect as recommended later in this paper are expected to be applicable to most red pine and aspen stands in Minnesota. Rocky, organic, or clay soils may be exceptions. But because no other information is available, the recommendations given may be used as rough guidelines for these kinds of soils. Sampling of these soils should be followed by statistical analysis (Appendix, page 5) to verify the applicability of the guidelines.

Number of Samples

The basic statistic used to compare variability of different soil properties is the coefficient of variation (*cv*) (Appendix, table 3). It is used to com-

pute the number of samples needed to estimate the mean of a given soil property within specified limits of confidence. The method of calculating n is detailed in the Appendix, page 5.

Soil nutrients tend to be more variable than soil physical properties or pH. For example, in mineral soil, bulk density, pH, and sand content can be estimated with just a few samples, whereas other properties (particularly P, Ca, and Mg) require many more (Appendix, Fig. 1 and table 4). This corroborates results from both agricultural soils (Beckett and Webster 1971) and other forest soils (Ike and Clutter 1968, Metz *et al.* 1966).

For the soil properties examined there was no statistical difference in the mean number of samples needed between red pine and aspen, or between the two layers of mineral soil. Therefore for each property the number of samples needed to estimate the mean within 10 percent was calculated by averaging the numbers for both species and both soil layers (table 1). The properties break into four groups ranging in

sample numbers needed from 2 for the least variable to 60 for the most variable. Soil P is by far the most variable soil property whether extracted by a weak reagent (0.01N HCl) or a stronger reagent (Bray's No. 1).

These numbers do not mean that to estimate soil P, for example, 60 samples must be collected and analyzed separately. The 60 collected soil samples could be composited into a single sample for laboratory analysis. But sometimes it may be desired to compare the means of a given soil property among several stands or in the same stand before and after some kind of treatment such as burning. Then samples should be randomly composited into a minimum of three samples for laboratory analysis. This will allow the precision of the estimated mean to be determined, and thus allow statistical comparison between means (Appendix, page 6).

The number of samples needed to estimate the mean of several forest floor properties within 10 percent were calculated for each of the six stands samples (table 1).

Table 1.--*Soil samples needed to estimate the mean of several soil properties^{1/} (the mineral soil values are applicable to both red pine and aspen stands and to surface soils as well as subsoils)*
(In numbers)

Soil property	Mineral soil		Forest floor ^{2/}	
	: Proposed		: (average)	
	: Average	: by groups	: Aspen	: Red pine
Bulk density	2		-	-
Sand	2	2	-	-
pH	2		2	2
Silt + clay	18		-	-
Nitrogen	18		11	33
ΔH_2O	26	25	-	-
Potassium	27		22	29
Calcium	41		25	50
Magnesium	41	40	17	32
Phosphorus (Bray 1)	60		23	39
Phosphorus (0.01N HCl)	61	60		
Ovendry weight	--	--	16	34
Ash	--	--	9	42

^{1/} Within 10 percent of the mean at the 95 percent confidence level. To estimate the number of samples needed to estimate means within limits other than ± 10 percent, multiply the n values by $\frac{100}{(\text{desired percent})^2}$. For example, to calculate

the number of samples needed to estimate phosphorus ± 20 percent, multiply $60 \frac{100}{(20)^2} = 15$ samples.

^{2/} Forest floor nutrient analysis was for total amounts rather than for extractable forms.

Forest floor pH under either species can be estimated to ± 10 percent with only two samples whereas other properties require more intensive sampling. Most properties under red pine require 30 to 50 samples; only half as many are needed under aspen. This is in sharp contrast to mineral soil where species differences were minimal. Other unpublished studies in Minnesota have found average *cv*'s for red pine forest floor weight to be 23 percent (50 stands) and for aspen 16 percent (15 stands), indicating that the species difference is real. Ovington (1954) found the forest floor to be unevenly distributed over the ground and, especially under conifers, to be thickest around tree boles. Pine needles, because of their shape, tend to disperse less than aspen leaves when they fall, and to be moved around less by wind after reaching the ground.

Like mineral soil samples, all forest floor samples can be composited into a single sample for analysis, or, if an estimate of the precision of the estimated mean is desired, the samples can be randomly composited into a minimum of three samples.

The time involved in digging even small soil pits prompted an examination of the use of soil sampling tubes. Small pits for sampling surface soils can be dug and sampled in 2 to 3 minutes each, but tube samples can be collected in 15 to 30 seconds each.

As a general guide, soil nutrients (except N) can be estimated adequately with about twice as many tube as pit samples (Appendix, table 5). For other, less variable properties, the number of tube samples should be the same as for pits.

Tube sampling, of course, cannot be effectively used in rocky soils or soils with dense root concentrations. Further, the kinds of tubes normally used for sampling (Jackson 1958) are not suitable for collecting bulk density samples, so this property must be determined separately.

Seasonal Variation

Soil properties vary not only spatially but may also vary seasonally. However, seasonal variation is nearly always much lower than spatial variation

(Cameron *et al.* 1971). The large spatial variation usually obscures any seasonal effects even when intensive sampling is used (Ball and Williams 1968, Frankland *et al.* 1963).

The 3 red pine stands in which soil variability was measured were among 61 stands in Minnesota from which soil samples were collected. About one-third of the 61 stands were on the 5 soil series mentioned earlier. Nearly all of the others had soil properties that fell within the ranges reported in table 2 (Appendix). Each stand was sampled only once, but the sampling of the 61 stands extended throughout the growing season (June through October). The stands were sampled in a random manner such that each month was represented by stands scattered throughout the geographical range of the study. The average site index of the stands was not significantly related to the month of sampling, suggesting that stands sampled in each month represented the same population.

Statistical analysis (F tests of the means) showed that of all forest floor and mineral soil properties tested (pH, N, P, K, Ca, Mg, Silt + clay, and ΔH_2O), only pH was related to the month of sampling. And, although the seasonal effects on pH were significant, the actual differences were small. For example, in the 0 to 10 inch layer, samples collected from June through October had average monthly pH values of 5.64, 5.40, 5.51, 5.57, and 5.31. Soil pH varies less than most soil properties (Appendix, table 3), and this allows the detection of seasonal variation that for the other properties is masked by large spatial variation.

The small contribution of seasonal variability to the total variance, as indicated by our red pine data and the literature, means that sampling throughout the growing season will result in only small errors for the properties we examined. However, sampling should be completed before leaf fall in the autumn because major changes in the L horizon of the forest floor occur at this time.

Laboratory Analysis Variation

Laboratory analysis variation is usually a minor component of total soil variability (Jacob and Klute 1956), and if too

large can usually be reduced by modifying the procedure or by running more duplicates. In the present study each analysis was run in duplicate or triplicate, allowing an estimate of laboratory variation. The *cv*'s for all properties were less than 3 percent and for pH was only 0.5 percent, clearly showing that laboratory variation contributes little to total soil variation.

Size of Area

Large areas usually have greater soil variability than small areas of course, but the importance of area size may easily be overemphasized. In either mineral soil (Beckett and Webster 1971) or the forest floor (Frankland *et al.* 1963), a large part of the total variance occurs within a few meters. For many studies summarized by Beckett and Webster (1971), *cv*'s rarely more than doubled from small plots (< than 0.02 acre) to large fields (200 acres). Thus, the results obtained in the present study (0.2 acre plots) could be utilized on typical forest management tracts (areas less than 40 acres) with little likelihood of serious error, if major differences in soil or vegetation types do not exist in the area.

SUMMARY AND CONCLUSIONS

Some soil properties are much more variable than others. In mineral soil, pH, bulk density, and sand content are relatively uniform whereas the soil nutrients are more variable. There is little difference in the variability of the mineral soil under aspen and under red pine, or in the variability of the surface and subsoil. Forest floor pH varies little. All other forest floor properties vary greatly, and about twice as many samples are required under red pine as under aspen to estimate the mean value with the same precision.

Estimating most soil nutrients required twice as many samples when using a cylindrical sampling tube instead of digging small soil pits. However, for the less variable soil properties (pH, particle size, and available water) sampling with tubes or pits required about the same number of samples.

Laboratory analysis variation is a minor component of the total soil variance. Similarly, seasonal changes in the soil properties measured are minor and much less important than spatial variation. This means that samples can be collected throughout the growing season without introducing major sources of error.

The results presented are directly applicable to small plots (0.2 acre), but literature reports suggest that the results can be extended to areas of 40 acres with little likelihood of serious error.

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APPENDIX

Methodology

Field Sampling

In each of three red pine and three aspen stands intensive soil sampling was done on a single 0.2 acre plot. Soil sampling points were located systematically from the plot center along the cardinal directions. If a sampling point occurred on a fallen log or directly beneath a tree bole, the point was moved 6 feet to the north. A detailed review of soil sampling methods and rationale is given by Petersen and Calvin (1965).

On each of the three red pine plots ten 1-foot square samples of the forest floor were collected and 10 soil pits dug directly beneath the sampled forest floor. A single sample was collected from each pit from the 0 to 10 inch layer and another from the 10 to 40 inch layer. About 1 quart of soil was removed for analysis from each layer; the sample was collected from throughout the layer and from all four sides of the pit. The three aspen plots were sampled similarly except that six forest floor and six soil pits were sampled per plot.

Soil bulk density (D_b) was measured from only two pits per plot because of expected low variability. From each pit three bulk density samples were taken (by the core method: core volume = 140 cm³) from the 0 to 10 inch layer and three from the 10 to 40 inch layer.

The 0 to 10 inch layer was also sampled on each plot using a 1-inch diameter cylindrical sampling tube in order to compare the variation of sampling by tubes with that by soil pits. On each plot 10 systematically located tube samples, each consisting of a single core from the sampler, were collected.

Laboratory Analysis

Forest floor samples were dried at 70° C and ground to pass a 20-mesh screen. Separate aliquots of the ground samples were: (1) analyzed for nitrogen by the Kjeldahl method, and (2) ashed at 525° C and the ash dissolved in dilute HCl. Calcium, Mg, and K were determined in the dissolved ash by atomic absorption spec-

troscopy. Phosphorus was determined colorimetrically.

Mineral soil samples were air dried, sieved through a 2 mm screen and the less than 2 mm material used for subsequent analysis. The material greater than 2 mm comprised less than 4 percent of the total sample weight. Nitrogen was determined by the Kjeldahl method. Calcium, Mg, and K were extracted with 1N NH₄OAc and determined by atomic absorption. Phosphorus was extracted with 0.01N HCl (Alban 1972) and Bray's No. 1 reagent (Bray and Kurtz 1945) and determined colorimetrically. Particle size analysis was done by hydrometer, and available water (ΔH_2O) was estimated from sieved samples as the difference between water held at 0.1 and 15 bars in standard moisture tension apparatus.

Standard statistical techniques were used to derive coefficients of variation (cv) for each property and to compute the number of samples needed to adequately predict the mean of each property.

Calculation of Number of Samples

The number of samples needed to estimate the mean of a soil property is calculated from the following formula:

$$n = \frac{t^2(CV)^2}{E^2},$$

where: n = The number of soil samples to collect.

CV = Coefficient of variation. A measure of the variation in the sample.

E = A specified error as percent of the mean. Most often is soils work the error is specified as 10 percent of the mean.

t = A statistic dependent on the number of samples and on the desired level of confidence. In soils we generally work at the 95 percent confidence level and at this level t values are as follows:

Samples (No.)	t value
3	4.3
5	2.8
10	2.2
15	2.1
20	2.1

Beyond 20 samples t stays constant at about 2. For most soil sampling problems we can assume $t=2.0$ with only minor errors introduced.

Example.—To calculate the number of samples needed to estimate the mean of soil K within 10 percent at the 95 percent confidence level for the 0 to 10 inch soil layer:

$CV=0.19$ Appendix table 2
 $E=0.10$ Specified error
 $t=2.0$ Assumed value

$$= \frac{(2.0)^2 (0.19)^2}{(0.10)^2} = 14 \text{ samples.}$$

Calculation of the Precision of the Mean

Assume that 60 soil samples have been collected from the 0 to 10 inch layer in a red pine stand as recommended in table 1 in order to estimate soil P. The samples were randomly composited into three samples for laboratory analysis which resulted in soil P values of 105, 110, and 115 pounds per

acre, or an average soil P value of 110 pounds per acre. To estimate the precision of the mean use the following equation:

Mean soil P value $\pm (t)$ (standard error)

where: $t=4.3$ (with $n=3$, and at the 95 percent confidence level)

$$\begin{aligned} \text{standard error} &= \frac{\sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}}}{\sqrt{n}} \\ &= \sqrt{\frac{(105-110)^2 + (110-110)^2 + (115-110)^2}{3-1}} \\ &\quad \sqrt{3} \\ &= 2.88, \end{aligned}$$

therefore
 soil P = $110 \pm (4.3)(2.88)$ or
 110 ± 12 pounds per acre.

Table 2.--Stand, site, and soil characteristics for three red pine and three trembling aspen stands in Minnesota

Species and soil series	FOREST FLOOR													
	Age	SI	pH	N	P	K	Ca	Mg	Oven-dry weight	Ash	Bulk density	Clay	Silt	Sand
	Yr.	Ft.							lb/acre	Per-cent	g/cm ³	Percent	Percent	Percent
Red pine														
Menahga	49	60	4.7	396	36	54	320	45	45	43				
Zimmerman	50	57	4.3	267	22	30	146	24	27	27				
Hiwood	72	57	4.5	421	38	54	340	54	54	40				
Aspen														
Hiwood	40	71	5.4	546	19	50	581	74	62	61				
Chisholm	22	80	5.2	691	26	77	717	77	64	53				
Faunce	44	64	6.0	616	18	53	880	97	44	35				
Average both species	46	65	5.0	490	26	53	498	62	49	43				
MINERAL SOIL (0 TO 10 INCHES)														
Red pine														
Menahga			5.5	1,002	1/106(574)	112	881	83	2,870	1.29	5	8	87	6
Zimmerman			5.4	1,221	131(675)	126	908	93	2,920	1.31	4	9	87	6
Hiwood			5.1	1,462	29(542)	123	647	86	2,850	1.28	5	26	69	12
Aspen														
Hiwood			5.3	1,446	120(550)	147	878	117	2,780	1.25	6	20	74	14
Chisholm			5.3	918	70(229)	107	702	73	3,050	1.37	8	23	69	16
Faunce			5.7	1,600	39(179)	152	1,600	224	3,030	1.36	6	7	87	6
Average both species			5.4	1,275	82(458)	128	936	113	2,920	1.31	6	15	79	10
MINERAL SOIL (10 TO 40 INCHES)														
Red pine														
Menahga			5.4	814	155(339)	271	1,938	271	9,690	1.45	4	1	95	2
Zimmerman			5.6	996	493(1,158)	285	1,983	237	9,490	1.42	4	2	94	3
Hiwood			5.0	1,263	381(743)	177	1,747	362	9,290	1.39	3	22	75	10
Aspen														
Hiwood			5.8	1,328	589(944)	299	1,552	224	9,350	1.40	4	13	83	11
Chisholm			5.5	2,161	892(157)	1,112	16,990	4,248	10,490	1.57	22	34	44	14
Faunce			7.3	1,746	81(283)	373	19,575	1,352	10,090	1.51	6	2	92	2
Average both species			5.8	1,385	432(604)	420	7,298	1,116	9,730	1.46	7	12	81	7

1/ First value is P extracted with 0.01N HCl. Value in brackets is P extracted with Bray's No. 1 solution.

Table 3.--*Coefficients of variation of forest floor and mineral soil properties under red pine and aspen*

FOREST FLOOR												
Sample identification	: pH	: N	: P	: K	: Ca	: Mg	: Oven- dry weight	: Ash	: Bulk density	: Sand	: Silt + Clay	: ΔH_2O
Red pine												
Menahga	5.6	20	31	21	41	32	30	30				
Zimmerman	4.4	24	22	20	20	19	24	19				
Hiwood	3.4	31	28	30	29	23	24	34				
Average	4.5	25	27	24	30	25	26	28				
Aspen												
Hiwood	2.7	8	8	8	13	8	14	8				
Chisholm	2.8	17	26	24	16	19	17	6				
Faunce	3.1	9	12	13	23	15	11	15				
Average	2.9	11	15	15	17	14	14	10				
Average both species	3.7	18	21	19	24	19	20	19				
MINERAL SOIL (0 TO 10 INCHES)												
Red pine												
Menahga	4.6	7	20	19	34	23			6.7	2.5	17	12
Zimmerman	3.0	13	15	17	24	16			1.3	2.4	15	23
Hiwood	4.8	18	41	24	30	34			4.9	5.3	12	16
Average	4.1	12	26	20	29	24			4.3	3.4	15	17
Aspen												
Hiwood	5.9	9	31	20	35	32			5.7	4.8	14	9
Chisholm	2.9	9	24	20	16	20			2.8	8.9	19	14
Faunce	5.6	20	39	15	28	15			4.2	2.5	17	26
Average	4.8	13	31	18	26	22			4.2	5.4	17	16
Average both species	4.5	13	28	19	28	24			4.3	4.4	16	17
MINERAL SOIL (10 TO 40 INCHES)												
Red pine												
Menahga	3.5	15	25	21	29	45			4.8	1.2	22	24
Zimmerman	1.3	19	25	18	17	11			5.2	1.5	23	35
Hiwood	5.8	23	37	30	26	31			2.5	3.0	9	8
Average	3.5	19	29	23	24	29			4.2	1.9	18	22
Aspen												
Hiwood	5.9	14	42	17	24	24			2.2	4.2	20	12
Chisholm	7.4	19	18	27	8	22			3.7	8.5	7	12
Faunce	1.1	30	41	27	34	28			0.8	2.0	24	37
Average	4.8	21	34	24	22	25			2.2	4.9	17	20
Average both species	4.2	20	31	23	23	27			3.2	3.4	18	21

Table 4.--Mineral soil samples needed to estimate mean ± 10 percent at
95 percent confidence level
(In numbers)

0 TO 10 INCHES											
Species and soil series	pH	N	P (0.01N HCl)	P Bray's	K	Ca	Mg	Bulk density	Sand	Silt + clay	ΔH_2O
Red pine											
Menahga	1	2	21	11	18	60	28	3	1	14	8
Zimmerman	1	8	12	11	16	30	13	1	1	11	28
Hiwood	1	16	87	68	28	45	60	2	1	7	12
Aspen											
Hiwood	1	6	38	83	25	18	27	1	5	25	12
Chisholm	2	6	74	69	26	80	66	2	2	13	5
Faunce	2	26	103	20	16	51	16	1	1	19	45
Mean both species	1	11	56	44	22	47	35	2	2	15	18
10 TO 40 INCHES											
Red pine											
Menahga	1	12	32	44	22	42	105	2	1	25	30
Zimmerman	1	19	32	86	16	15	6	2	1	29	63
Hiwood	2	28	80	121	44	36	49	1	1	4	3
Aspen											
Hiwood	4	23	21	58	49	4	32	1	6	3	9
Chisholm	2	12	120	67	18	39	39	1	1	26	10
Faunce	1	62	111	84	48	77	50	1	1	37	89
Mean both species	2	26	66	77	33	36	47	1	2	21	34

Table 5.--Soil samples collected from pits
or tubes necessary to estimate mean of
soil property ± 10 percent (at 95
percent level) in the 0 to 10 inch layer
of mineral soil
(In numbers)

Soil property	Pits		Tubes		Difference of means
	Mean ^{1/}	Range	Mean ^{1/}	Range	
pH	1	1 - 2	2	1 - 4	1
N	11	2 - 26	13	6 - 24	2
P (0.01N HCl)	56	12 - 103	116	31 - 281	60
K	22	16 - 28	39	22 - 75	17
Ca	47	30 - 80	62	9 - 147	15
Mg	35	16 - 66	57	4 - 168	22
Silt + clay	15	7 - 25	10	3 - 17	-5
Sand	2	1 - 5	1	1 - 2	-1
ΔH_2O	18	5 - 45	22	5 - 62	4

^{1/} The mean of three red pine and three aspen stands.

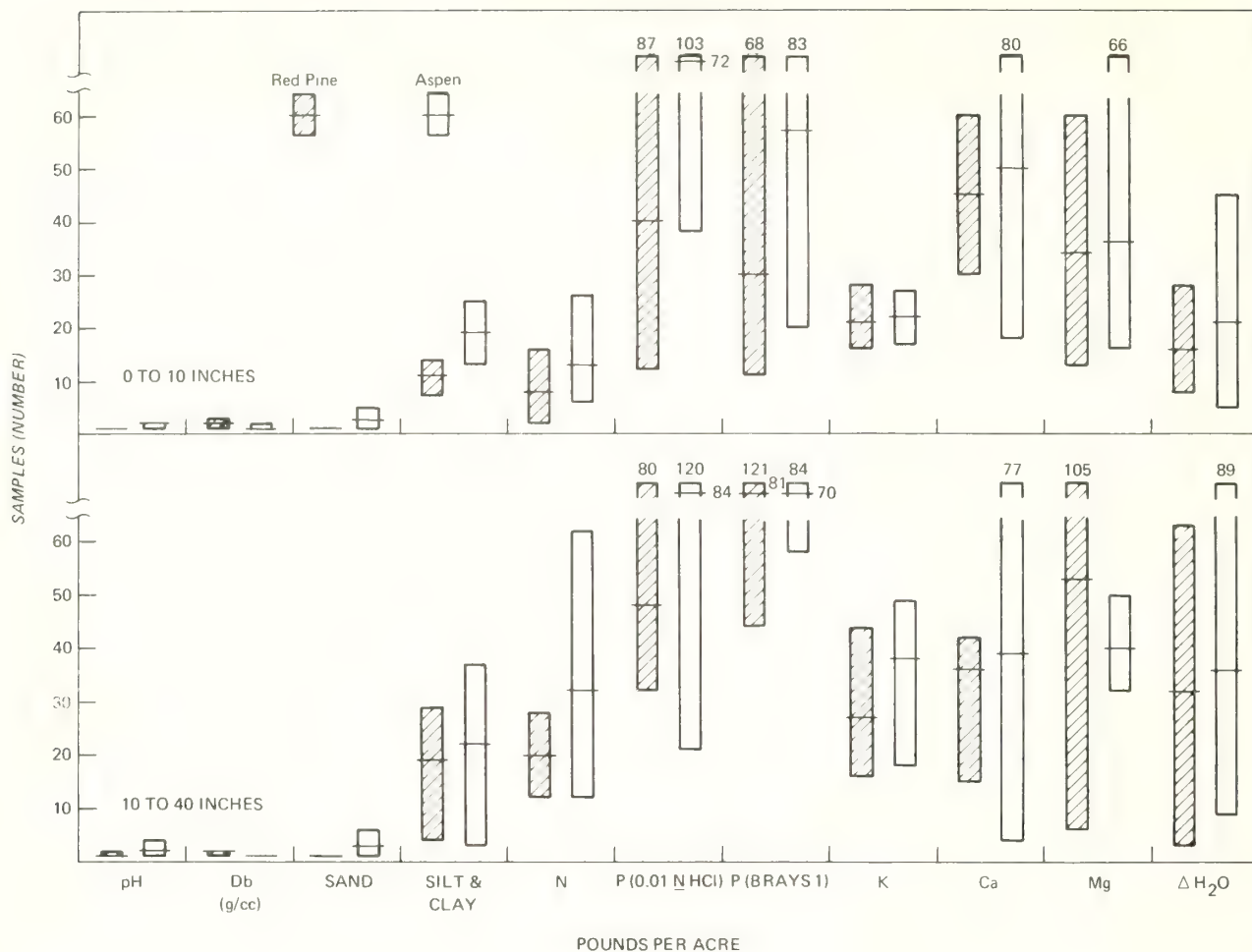
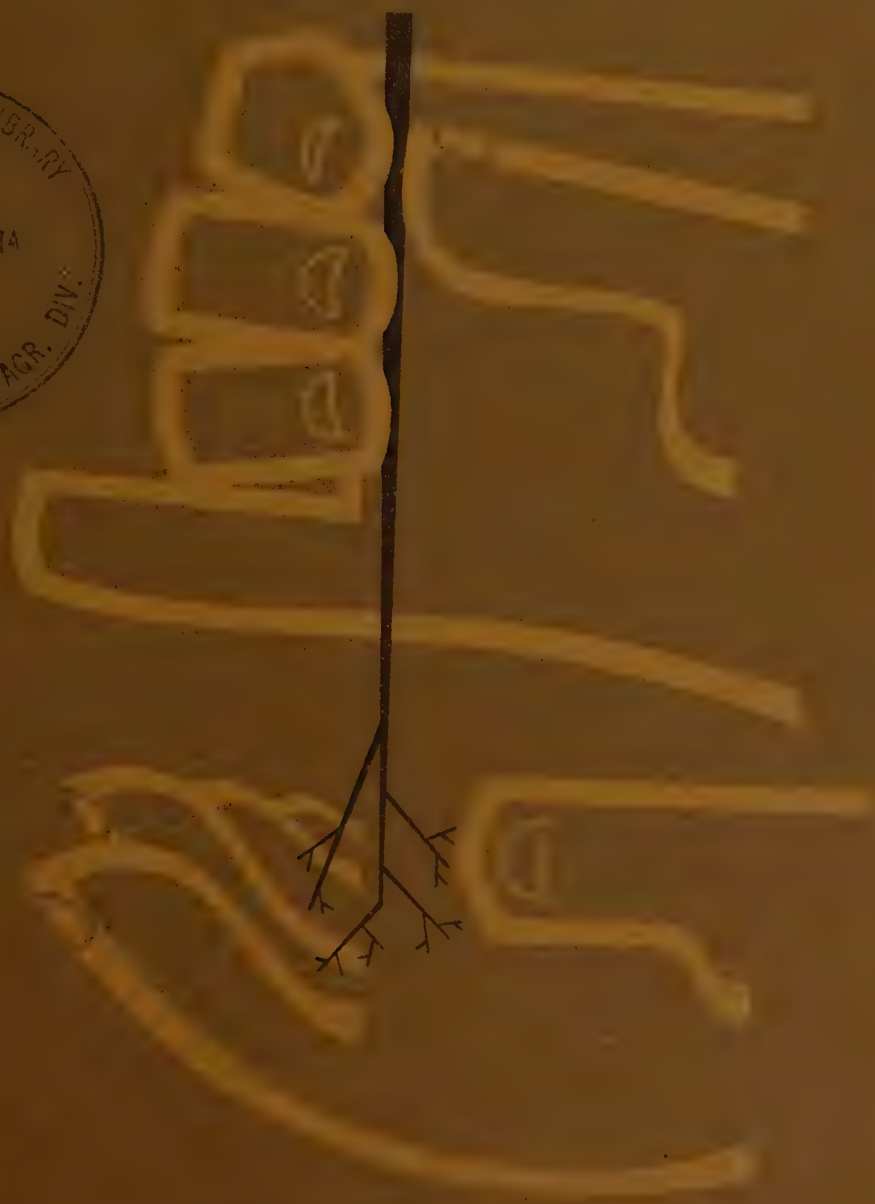


Figure 1.--Number of mineral soil samples needed to estimate mean ± 10 percent at 93 percent confidence level. The extent of each bar represents the minimum and maximum of three sites, and the horizontal line through each bar indicates the mean of all three sites.



Sing along with Woodsy and help stop pollution.

PLANTING METHODS & TREATMENTS FOR BLACK WALNUT SEEDLINGS ROBERT D. WILLIAMS



CONTENTS

Cleared-Forest Site	1
Open-Field Plantings	3
Discussion and Conclusions	4
Pesticide Precautionary Statement	6

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PLANTING METHODS AND TREATMENTS FOR BLACK WALNUT SEEDLINGS

Robert D. Williams

Survival of planted black walnut seedlings usually has been good but early growth has been poor, especially during the planting year. Black walnut seedlings planted on good sites and given adequate weed control normally grow well during the second and succeeding years, but very few grow the first year; in fact, many die back. In an effort to get walnut seedlings to grow faster, earlier, we planted different size, 1- and 2-year-old, pruned and unpruned seedlings by various methods on forest and field sites. Results from four experimental plantings show that planting method has little effect on survival or early growth of black walnut seedlings.

The study was begun in 1964 with a planting on a cleared-forest site in southern Indiana. Supplemental plantings were established in succeeding years on open-field sites in southern Illinois.

CLEARED-FOREST SITE

Methods

The cleared-forest planting site was prepared by clearcutting an opening on the lower half of a forested, north-facing slope in southern Indiana. Walnut seedlings were planted no closer than 75 ft to the trees on the perimeter of the opening. Except for some large cull logs left by the loggers, stems and tops were removed from the planting area. Stumps smaller than 12 in. in diameter were treated with an herbicide to control sprouting. With the exception of a planting-year simazine treatment on some plots, competition was not controlled.

Four planting spot treatments were randomly assigned in each of four contiguous blocks on the cleared-forest area:

1. Check--no treatment.

2. Fertilizer--3 oz of 8-32-8 per tree. One oz was applied in the planting hole, and 2 oz were broadcast in a cultivated, 3-ft-diameter circular area around each tree a month later.

3. Simazine--4 lb of 80 percent wettable powder per acre applied in a 4-ft cultivated strip with the seedlings planted in the center of the strip.

4. Fertilizer plus simazine--applied as indicated for treatments 2 and 3.

Ten combinations of planting methods, seedling age and size, and seedling pruning treatments were assigned at random to ten 10-tree rows within each of the 4 planting spot treatments in each of the 4 blocks:

Planting methods

10/32 In. Seedling Diameter^{1/}

Mattock slit: 8-in. root planted to root collar.

Hole:^{2/} 12-in. root planted to root collar.

Hole: 12-in. root, deep planted 4 in. above root collar.

Hole: 8-in. root planted to root collar.

Hole: 8-in. root, deep planted 4 in. above root collar.

Hole: 8-in. root, 1-in. top, planted to root collar.

16-18/32 In. Seedling Diameter

Hole: 12-in. root planted to root collar.

Hole: 12-in. root, deep planted 4 in. above root collar.

Hole: 8-in. root planted to root collar.

Hole: 8-in. root, 1-in. top, planted to root collar.

^{1/} One inch above the root collar.

^{2/} Holes for the center hole method were dug with a planting mattock.

Seedlings planted on the cleared-forest site were grown at the now abandoned Clark State Nursery in Southern Indiana.

The smaller seedlings survived as well as the larger seedlings, but the larger seedlings were taller after 4 yr (table 1).^{3/}

Fourth-Year Results

Fertilization reduced survival and height growth. Average fourth-year survival ranged from 74 percent for fertilized

Planting method had little effect on fourth-year survival or growth (table 1). Regardless of the planting method used, survival was good and height growth was poor. Poor height growth may be attributed to lack of weed control.

^{3/} Robert D. Williams. Plant large black walnut seedlings for best survival and growth. Cent. States For. Exp. Stn., CS-38. 1965.

Table 1.--Fourth-year survival and height by planting method and planting spot treatment on the cleared-forest site

10/32 INCH DIAMETER SEEDLINGS								
Planting method and seedling size	Planting spot treatment							
	Check		Simazine		Fertilizer		Fert. + Sim.	
	Survival	Height	Survival	Height	Survival	Height	Survival	Height
	Percent	Feet	Percent	Feet	Percent	Feet	Percent	Feet
Mattock slit, 8 in. root, normal	90	3.2	95	4.4	80	3.0	80	4.1
Center hole, 12 in. root, normal	92	3.0	98	4.4	88	3.0	90	3.4
Center hole, 12 in. root, deep	92	3.0	80	3.9	65	2.4	65	3.1
Center hole, 8 in. root, normal	85	3.4	98	3.9	68	2.2	70	3.2
Center hole, 8 in. root, deep	98	3.0	92	3.3	75	2.5	88	4.6
Center hole, 8 in. root, 1 in. top	92	2.8	95	4.1	70	2.5	62	3.6
16-18/32 INCH DIAMETER SEEDLINGS								
Center hole, 12 in. root, normal	92	3.9	92	4.8	70	3.4	90	4.3
Center hole, 12 in. root, deep	98	3.5	90	4.0	65	3.5	80	4.5
Center hole, 8 in. root, deep	92	3.8	92	4.4	78	3.8	82	4.6
Center hole, 8 in. root, 1 in. top	95	3.5	95	3.5	82	3.5	88	4.5
Average of all planting methods	93	3.3	93	4.0	74	3.0	80	4.0

seedlings to 93 percent for those not fertilized (table 1). Mean height was 3.0 ft for the fertilized seedlings and 4.0 ft for those that received the simazine weed control treatment, either alone or in combination with fertilization.

The harmful effects of fertilizing walnut seedlings at planting time may be due either to the more vigorous overtopping vegetation stimulated by the fertilizer, or to the "burning" of seedling roots that come in direct contact with the fertilizer applied in the planting hole. Mortality was high in the fertilizer-plus-simazine spots but growth was not suppressed, indicating that root burn was the most likely cause of mortality in the fertilized spots.

Simazine alone did not increase survival over that of the check spots but controlling weeds did increase growth.

OPEN-FIELD PLANTINGS

Methods

Three open-field plantings were established on bottomland sites on the Kaskaskia Experimental Forest in southern Illinois in 1965, 1966, and 1967. The sites were plowed and disced before planting and competing vegetation was controlled by mechanical and chemical methods during the 4-yr course of the studies.

Seedlings for the open-field plantings were grown at the Jasper-Pulaski State Nursery in northern Indiana.

In 1965, 10/32-in.-diameter 1-0 seedlings and 14/32-in.-diameter 2-0 seedlings were planted. Roots of the 10/32-in. seedlings were pruned to 10 in. and those of the 14/32-in. 2-0 seedlings were pruned to 14 in. before planting.

In 1966 and 1967 only 1-0 seedlings in the 8/32-in.-diameter class were planted. Some of the seedlings planted in 1967 were infected with a root rot disease, and several died soon after planting. These and seedlings killed by an early spring flood were replanted by the assigned methods May 17, 1967.

With the exception of the 2-0 seedlings planted in 1965, planting methods were the same for the three open-field plantings:

Description

1965, 1966, and 1967 Plantings--1-0 Seedlings^{4/}

Bar-slit: 8-in. root, planted to root collar.
Auger hole: 8-in. root, planted to root collar.
Bar-slit: 12-in. root, planted to root collar.
Auger hole: 12-in. root, planted to root collar.
Auger hole: 12-in. root, deep planted to 6 in. above root collar.
Bar-slit: 8-in. root, 3-in. top, planted to root collar.
Auger hole: 8-in. root, 3-in. top, planted to root collar.

1965 Planting--2-0 Seedlings^{5/}

Auger hole: 14-in. root, planted to root collar.
Auger hole: 14-in. root, 3-in. top, planted to root collar.
Auger hole: 14-in. root, deep planted 6 in. above root collar.

1966 and 1967 Plantings--1-0 Seedlings^{4/}

Bar-slit: 8-in. root, laterals sheared to 1 in., planted to root collar.
Bar-slit: 8-in. root, laterals sheared to 1 in., 3-in. top, planted to root collar.
Auger hole: 8-in. root, laterals sheared to 1 in., 3-in. top, planted to root collar.

The seedlings were planted with planting bars or in holes bored with a tractor-mounted, 9-in.-diameter auger.

^{4/} 1-0 seedlings planted in 1965 were 10/32-in. diameter; 1-0 seedlings planted in 1966 and 1967 were 8/32-in. diameter.

^{5/} 2-0 seedlings planted in 1965 were 14/32-in. diameter.

In 1965 and 1966, each planting treatment was randomly assigned to six 10-tree rows in each block. Only five 10-tree rows of each planting treatment were planted in 1967.

In 1966, excessive spring rains and summer drought combined to kill many of the seedlings planted that year. Rainfall in April was 8.85 in. and in May 7.10 in., while rainfall in June and July was only 1.53 and 0.89 in., respectively.

Fourth-Year Results

Survival was related more to the year of planting than to planting treatment (table 2). Survival of seedlings planted in 1965 and 1967 by bar or in auger holes was about the same. However, in 1966 more bar-planted trees survived than trees planted in auger holes. Survival was reduced when secondary seedling roots were

sheared to 1 in. before planting. The 2-0 seedlings planted in 1965 did not survive any better than the 1-0 seedlings, even though roots of the 2-0 seedlings were 4 in. longer. Top pruning had little effect on survival. Deep planting did not improve survival or growth. In fact survival of deep-planted seedlings was only 22 percent in 1966, poorest of any treatment in the open-field plantings.

Height and diameter differences among planting treatments were not consistent. However, 4-year-old bar-planted trees in 1966 and 1967 did show a height advantage (table 2).

DISCUSSION AND CONCLUSIONS

Results on the cleared-forest site and the open-field sites should not be compared directly because the plantings

Table 2.--Fourth-year survival, height, and diameter of three open-field plantings on the Kaskaskia

Planting method and seedling size	Year planted								
	1965			1966			1967		
	Survival	Height	DBH	Survival	Height	DBH	Survival	Height	DBH
	Percent	Feet	Inches	Percent	Feet	Inches	Percent	Feet	Inches
Bar, 8 in. root	97	10.3	1.4	80	9.9	1.4	84	10.6	1.4
Hole, 8 in. root	100	11.3	1.6	62	9.5	1.4	94	10.4	1.2
Bar, 12 in. root	94	9.7	1.3	70	10.1	1.4	96	12.4	1.8
Hole, 12 in. root	100	8.9	1.2	47	8.7	1.3	92	10.6	1.3
Hole, 12 in. root, deep planted	94	9.0	1.2	22	9.4	1.4	76	9.4	1.1
Bar, 8 in. root (3 in. top)	92	8.9	1.2	68	9.8	1.5	82	10.7	1.4
Hole, 8 in. root (3 in. top)	95	9.6	1.6	52	9.3	1.3	92	10.7	1.2
Hole, 2-0	100	9.7	1.2						
Hole, 2-0, 3 in. top	93	11.6	1.5						
Hole, 2-0, deep planted	87	10.5	1.4						
Bar, 8 in. root (sheared)				52	9.3	1.2	78	10.8	1.4
Bar, 8 in. root (3 in. top, sheared)				72	9.8	1.4	74	11.4	1.4
Hole, 8 in. root (3 in. top, sheared)				47	10.0	1.4	74	11.0	1.3

were made in different years, at widely separated locations with seedlings grown at different nurseries. Also, competing vegetation was controlled on the open-field sites, but not on the cleared-forest site. The greater height growth on the open-field sites does indicate the value of weed control.

On the cleared-forest site where weeds were not controlled, fertilization reduced survival and growth of the planted trees. Seedling roots probably were burned by the fertilizer salts that were placed in the planting hole, but it was apparent, too, that competing weeds, stimulated by the fertilizer, suppressed some walnut seedlings. Evidently, walnut seedlings should not be fertilized at planting time.

Simazine used in combination with fertilizer did not adequately control the weeds and woody vegetation stimulated by fertilization; however, simazine alone and in combination with fertilization increased tree height. Results from weed-control studies have shown that tree growth was increased most when the herbicides were applied annually for at least 2 yr.^{6/} On the cleared-forest site, simazine was applied only once--immediately after planting--so weed control was not adequate.

There were no clear-cut differences in survival or growth among planting methods. However, in 1966, when early spring rains were excessive, bar-planted trees survived better than those planted in auger holes. It seems likely that water accumulated in the auger holes and drowned the newly planted seedlings. These results indicate that bar planting usually should be preferred to auger planting because bar planting is faster and cheaper.

^{6/} John E. Krajicek and Robert D. Williams. *Continuing weed control benefits young planted black walnut.* USDA Forest Serv. Res. Note NC-122, 3 p. North Cent. For. Exp. Stn., St. Paul, Minn. 1971.

Deep-planted seedlings survived and grew about as well as those planted at normal depth, but no better. So, because deep planting takes more time, and there's a possibility of root rot with no apparent benefits, we must recommend normal-depth planting.

Two-year results from a more recent planting-methods study showed that seedlings planted by machine survive and grow as well as those planted by other methods. However, it was necessary that a man follow the machine to straighten the stems and firm the soil around the seedling roots. Our experience with machine planting is limited to this one planting. So even though survival and growth of machine-planted trees were satisfactory, the method should be tested in other years, at other locations, and on different size seedlings before machine planting can be recommended for planting black walnut.

Stem pruning black walnut seedlings before planting had little effect on survival or mean height. This suggests that seedling stems could be pruned at the nursery to make packing and shipping of the faster growing, large diameter seedlings less difficult.

Two-year-old seedlings did not survive or grow any better than 1-0 seedlings. Although the added expense to produce 2-0 seedlings is not justified, nurserymen need not hesitate to carry surplus 1-0 stock another year.

Shearing secondary roots of black walnut seedlings caused a small decrease in survival, so shearing is not recommended.

These results indicate that the best planting method for black walnut is the one most convenient for the planter as long as it is compatible with the type of planting stock. The planting method can vary according to the equipment on hand, the size and topography of the site, the soil condition and existing vegetation on the site, and the size of the planting stock.

PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife--if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.



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site index prediction table for black, scarlet, & white oaks in southeastern missouri



robert a. mcquilkin

NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE

CONTENTS

Application	1
Documentation	5
Tree selection	5
Stem analysis	5
Statistical analysis	5
Comparison of site index among species	6
Comparison of site index curves	7
Computation of the confidence intervals	7
Literature Cited	8

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SITE INDEX PREDICTION TABLES FOR BLACK, SCARLET,
AND WHITE OAKS IN SOUTHEASTERN MISSOURI

Robert A. McQuilkin

A P P L I C A T I O N

Site index prediction tables were prepared for black, scarlet, and white oak from stem analyses of 741 sectioned trees. These tables were specifically designed to predict site index given tree height and age, and thus differ from conventional site index curves, which show height growth by age and site index.

Confidence intervals, derived from the same data, show the range within which the true mean stand site index is expected to fall for the number of trees measured, the age of the trees, and the probability level.

To estimate the site index of an even-aged oak stand:

1. Delineate a stand that is relatively uniform in site index and tree age.

2. Determine the number of sample trees needed for the desired precision from table 1 or 2.

3. Select as sample trees only straight, undamaged dominant or codominant trees that show no sign of past suppression.

(Sample trees should be similar in age (i.e., differences less than 5 years) to the trees immediately surrounding them. Current research shows that trees older or

younger than those around them have different height growth patterns and thus indicate erroneous site indexes. These age differences are sometimes difficult to detect without increment borings because, unless the age differences are large, the trees tend to be similar in size and appearance to the surrounding trees. To ensure that they are similar in age to the trees around them, sample trees should be taken in randomly located groups of 2 or 3. Age differences *between groups* are not important.)

4. Measure tree height and breast-height age; add 2 years to breast-height age to get total age.

5. Keep sample trees separate by the three species; if all sample trees are of one species, calculate the average height and age and read the site index from table 3 or 4. If the sample trees are of more than one species, conversions should be made and all site indexes expressed as equivalent site index of one species before averaging. For most areas, black oak is the best standard site index species to use. Conversions between species may be made as follows:

Black oak SI = Scarlet oak SI - 3.
Scarlet oak SI = Black oak SI + 3.
Black oak SI = White oak SI + 4.
White oak SI = Black oak SI - 4.

Table 1.--Confidence intervals for stand site index estimates from 3-, 5-, 10-, and 20-tree measurements at the 90 and 95 percent probability levels for black and scarlet oak at ages 10 to 80 years

90 PERCENT PROBABILITY									
n	Age (years)								
	10	20	30	40	50	60	70	80	
3	±12	±10	±8	±6	±4	±5	±7	±7	
5	±7	±5	±4	±3	±3	±3	±4	±4	
10	±4	±3	±3	±2	±2	±2	±2	±2	
20	±3	±2	±2	±1	±1	±1	±2	±2	
95 PERCENT PROBABILITY									
3	±17	±14	±12	±8	±7	±8	±10	±11	
5	±9	±7	±6	±4	±3	±4	±5	±5	
10	±5	±4	±3	±2	±2	±2	±3	±3	
20	±3	±3	±2	±2	±1	±1	±2	±2	

The confidence intervals (tables 1 and 2) show the range within which the true (but unknown) mean stand site index is expected to fall at the given probability level. For example, if the average height of five 30-year-old white oak trees is 38 feet, the estimated site index is 55 feet (table 4), and the 90 percent confidence interval is ± 4 feet (table 2). Thus the true mean stand site index is expected (with a 90 percent probability) to fall

Table 2.--Confidence intervals for stand site index estimates from 3-, 5-, 10-, and 20-tree measurements at the 90 and 95 percent probability levels for white oak at ages 10 to 80 years

90 PERCENT PROBABILITY									
n	Age (years)								
	10	20	30	40	50	60	70	80	
3	±9	±8	±7	±5	±4	±5	±6	±5	
5	±5	±5	±4	±3	±2	±3	±3	±3	
10	±3	±3	±2	±2	±1	±2	±2	±2	
20	±2	±2	±2	±1	±1	±1	±1	±1	
95 PERCENT PROBABILITY									
3	±14	±12	±10	±8	±6	±7	±9	±8	
5	±7	±6	±5	±4	±3	±4	±4	±4	
10	±4	±4	±3	±2	±2	±2	±2	±2	
20	±3	±2	±2	±1	±1	±1	±2	±1	

within the range 55 ± 4 feet, but may (with a 10 percent probability) fall above or below this range.

Caution must be exercised in predicting site indexes based on very young trees because of the great variation in tree heights at young ages. This variability is shown in the confidence intervals of tables 1 and 2.

Table 3.--Black and scarlet oak site index estimates by 2-foot height and 2-year age intervals^{1/}

Age (years):	8:10:12:14:16:18:20:22:24:26:28:30:32:34:36:38:40:42:44:46:48:50:52:54:56:58:60:62:64:66:68:70:72:74:76:78:80:82:84:86:88:90:92
10	55 57 59 61 63 64 66 68 70 72
12	54 56 58 60 62 63 65 67 69 71
14	53 55 57 59 61 62 64 66 68 70 72 74
16	52 54 56 58 60 62 63 65 67 69 71 73 75
18	51 53 55 57 59 60 62 64 66 68 70 72 74 76 78
20	50 52 54 56 58 60 61 63 65 67 69 71 73 75 77 79
22	49 51 53 55 57 59 61 63 65 67 69 71 73 75 77
24	48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78
26	47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77
28	46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78
30	45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77
32	44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78
34	43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77
36	42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78
38	41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77
40	40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78
42	39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77
44	38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78
46	37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77
48	36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78
50	35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77
52	34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78
54	33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77
56	32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78
58	31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77
60	30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78
62	29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77
64	28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78
66	27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77
68	26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78
70	25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77
72	24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78
74	23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77
76	22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78
78	21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77
80	20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78

^{1/} All height and age combinations in this table are within the range of the original black oak data; height and age combinations within the lines indicate the range of the original scarlet oak data.

Table 4.--White oak site index estimates by 2-foot height and 2-year age intervals^{1/}

Age :	Height (feet)																							
(years)	10:12	14:16	18:20	22:24	26:28	30:32	34:36	38:40	42:44	46:48	50:52	54:56	58:60	62:64	66:68	70:72	74:76	78:80	82:84	86:88	90:92			
10	46	49	52	54	57	60	62	65	68															
12	44	47	49	52	54	57	60	62	65	68														
14	44	47	49	52	54	57	59	62	64	67	69													
16		44	47	49	52	54	56	59	61	64	66	68	71											
18		44	47	49	51	54	56	58	61	63	65	68	70											
20			44	46	48	51	53	55	57	60	62	64	66	69										
22			42	44	46	48	51	53	55	57	60	62	64	66	69	71								
24			42	44	46	48	51	53	55	57	59	62	64	66	68	71								
26			42	44	46	48	51	53	55	57	59	62	64	66	68	70								
28			42	44	46	48	50	53	55	57	59	61	64	66	68	70								
30			42	44	46	48	50	52	55	57	59	61	63	66	68	70								
32			40	42	44	46	48	51	53	55	57	59	61	64	66	68	70							
34			40	42	44	46	49	51	53	55	57	59	62	64	66	68	70							
36			40	42	45	47	49	51	53	55	57	60	62	64	66	68	70							
38			40	43	45	47	49	51	53	55	57	60	62	64	66	68	70							
40			41	43	45	47	49	51	53	55	58	60	62	64	66	68	70							
42			39	41	44	46	48	50	52	54	56	58	60	62	64	66	68	71						
44			40	42	44	46	48	50	52	54	57	59	61	63	65	67	69	71						
46			39	41	43	45	47	49	51	53	55	57	59	61	63	65	67	69	71					
48			39	41	43	45	47	49	52	54	56	58	60	62	64	66	68	70						
50			38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70					
52			39	41	43	45	47	49	51	53	55	57	59	61	63	65	67	69	71					
54			40	42	44	46	48	50	52	54	56	58	60	62	63	65	67	69	71					
56			39	41	43	45	47	49	51	53	55	56	58	60	62	64	66	68	70					
58			40	42	44	46	48	50	51	53	55	57	59	61	63	65	67	68	70					
60			39	41	43	45	47	48	50	52	54	56	58	60	61	63	65	67	69	71				
62			41	42	44	46	48	49	51	53	55	57	58	60	62	64	66	67	69	71				
64			40	42	43	45	47	49	50	52	54	56	57	59	61	62	64	66	68	69	71			
66			39	41	43	44	46	48	49	51	53	54	56	58	59	61	63	64	66	68	70			
68			39	40	42	44	45	47	49	50	52	54	55	57	58	60	61	63	65	66	68	69		
70			40	41	43	45	46	48	49	51	52	54	55	57	58	60	62	64	65	66	68	69		
72			39	41	42	44	46	47	49	50	52	53	55	56	58	59	61	63	64	66	67	69	70	
74			39	40	42	43	45	47	48	50	51	53	54	56	57	59	61	62	64	65	67	68	70	
76			40	41	43	45	46	48	49	51	52	54	55	57	58	60	62	63	65	66	68	69	71	
78			39	41	42	44	46	47	49	50	52	53	55	56	58	59	61	63	64	66	67	69	70	
80			39	40	42	43	45	47	48	50	51	53	54	56	57	59	60	62	64	65	67	68	70	71

^{1/} All height and age combinations to the left of the line are within the range of the original data; combinations to the right of the line are extrapolations.

DOCUMENTATION

Site quality in even-aged oak stands is usually expressed as site index--the height of the dominant and codominant trees at age 50. Unless the trees are exactly 50 years old, making direct measurements of site index on standing trees requires an accurate method of determining past or future 50-year heights from heights at ages other than 50. This determination is normally made with site index curves, which show the height/age patterns of trees of various site indexes. Properly constructed, such curves do accurately show height growth patterns, but the use of these curves is not the most accurate method of determining site index. Because of this, we recently developed "site index prediction tables" for three oak species (black, *Quercus velutina* Lam.; white, *Q. alba* L.; and scarlet, *Q. coccinea* Muenchh.) in southeastern Missouri from measurements of several hundred trees. This is how we did it.

Tree Selection

All study trees were located on the Clark and Mark Twain National Forests. Of the 741 trees used, 399 were black oak, 276 were white oak, and 66 were scarlet oak.

Trees were chosen from well stocked, even-aged, second growth oak-hickory and oak-pine stands. The trees were dominants or codominants at least 50 years old and showed no growth suppression or damage by fire, insects, or disease. All trees were single-stemmed, although trees with acute-angle forks in the tops were accepted. The trees were located on upland sites that differed widely in soil and topographic characteristics.

Stem Analysis

The trees were felled and sectioned at 4- or 8-foot intervals from the stump to the top of the tree. Height above ground and the number of annual rings were determined at each cutting point.

Because tree age for site index determinations is usually measured at breast height, most study trees were also sectioned at 4-1/2 feet so the difference between total age and breast-height age could be

determined. As a result, total age was reckoned to be breast-height age plus 2.

Age at each cutting point was determined by subtracting the ring count at that point from the total tree age. Height-age data for each tree were then plotted on a height/age graph from which the heights of the trees at 10-year intervals were determined.

These 10-year heights were then corrected for a slight inherent bias. The ring counts gave age at a specific height; however, the total height at a given age would be slightly greater than that shown because the cut presumably occurred somewhere in the middle of the height growth for that year. So, half the average annual height growth at that age was arbitrarily added to the 10-year heights to obtain corrected heights (Carmean 1972).

Statistical Analysis

Tree height/age/site index data can be analyzed by using height growth functions or site index prediction functions. These two methods produce basically different results, each of which is useful for a different purpose (Strand 1964).

Height growth functions (i.e., conventional site index curves), because of the way they are constructed, are best suited for determining future or past heights of trees of known site index. On the other hand, site index prediction functions are best suited for determining site index of trees of known height and age. Height growth functions have traditionally been used as site index predictors and, at ages near the index age, only small errors are introduced. At young ages, however, the errors introduced can be significant so site index prediction functions were used in this work.¹

¹Since this publication was prepared, an article has appeared which discusses this concept further: R. O. Curtis, D. J. DeMars, and F. R. Herman. Which dependent variable in site index-height-age regressions? *For. Sci.* 20: 74-87. 1974.

Linear regressions of the form:

$$\text{Site Index} = b_0 + b_1 (\text{height})$$

were computed for ages 10 through 80 for each of the three species (Johnson and Worthington 1963). The regressions were then compared by covariance analysis; differences between the black and scarlet oak regressions were nonsignificant so the data for these two species were combined. The black-scarlet regressions were significantly different from the white oak regressions, however, so these two species-groups were kept separate (table 5). The results of these regressions (plus interpolations between equations) were then arranged in the site index prediction charts (tables 3 and 4).

Comparison of Site Index Among Species

Although height growth patterns of black and scarlet oaks of equal site index were similar, black and scarlet oaks growing together showed significant differences in their mean site indexes. Regression equations relating site indexes between these two species on 47, 1/5-acre plots were:

$$\text{Scarlet oak site index} = 6.25 + 0.9450 (\text{black oak site index}).$$

$$\text{Black oak site index} = 0.82 + 0.9439 (\text{scarlet oak site index}).$$

The R^2 for these equations was 0.89.

Because of the nature of regression analysis, these two equations are not identical and each one will predict site index only for the species on the left side of the equation from the known site index of the species on the right side. In spite of this seemingly contradictory nature, these equations are the most accurate for such site index conversions. A simplified equation (derived by bisecting the angle between the two regression lines) resulted in one equation (expressed here two ways) that could convert site indexes both ways between species:

$$\text{Scarlet oak site index} = 2.79 + 1.0006 (\text{black oak site index}).$$

$$\text{Black oak site index} = -2.79 + 0.9994 (\text{scarlet oak site index}).$$

Table 5.--Statistics of the black-scarlet oak and white oak site index/height regressions for ages 10 to 80

BLACK-SCARLET OAK					
Age : (years)	Number : of trees	Intercept :	Slope :	R^2 :	Standard : error
10	465	44.68	0.990	0.21	0.30
20	465	29.83	.989	.49	.24
30	465	16.75	1.006	.72	.18
40	465	4.76	1.045	.91	.10
60	272	-1.57	.939	.95	.11
70	145	-1.21	.869	.87	.24
80	44	3.24	.768	.75	.50
WHITE OAK					
10	276	32.98	1.340	0.32	0.29
20	276	23.68	1.124	.48	.25
30	276	12.95	1.099	.74	.18
40	276	4.88	1.052	.92	.10
60	122	-1.61	.928	.93	.14
70	52	2.66	.775	.78	.33
80	34	-.15	.778	.85	.31

Further simplification can be made with little additional error by using the following approximation:

Scarlet oak site index =
black oak site index + 3.

Black oak site index =
scarlet oak site index - 3.

Similar analysis of black and white oak data from 67 plots showed significant differences in the mean site indexes. Regression equations relating these two species were:

Black oak site index =
 $12.49 + 0.8412$ (white oak site index).

White oak site index =
 $3.19 + 0.8876$ (black oak site index).

The R^2 for these equations was 0.75. Simplification of these two equations similar to that done for the black-scarlet oak data resulted in a single equation for converting black and white oak site indexes both ways:

Black oak site index =
 $5.02 + 0.9737$ (white oak site index).

White oak site index =
 $5.15 + 1.0270$ (black oak site index).

Conversion can be further simplified with little additional error by using the approximation:

Black oak site index =
white oak site index + 4.

White oak site index =
black oak site index - 4.

Scarlet and white oak occurred together on only three plots, so no comparisons could be made between these two species. The species-site index comparisons agree generally with similar published comparisons from other oak regions (Nelson and Beaufait 1956, Trimble and Weitzman 1956,

Doolittle 1958, and Olson and Della-Bianca 1959).

Comparison of Site Index Curves

These Missouri site index prediction tables were compared with the height growth curves of Schnur (1937) and Carmean (1971) over a wide range of heights and ages. As expected, for ages of about 50 years all three curves predicted similar site indexes for given heights and ages. At ages 10 and 20 however, differences in predicted site index were as much as 26 and 11 feet, respectively, between the Missouri site index prediction tables and the two regional height growth curves.

Analyzing the data by Heger's method (1968) (i.e., regressions of height on site index producing conventional height/age site index curves) showed that differences in tree height-growth patterns exist between the southern Missouri trees and those represented by either of the two regional curves, although the Missouri white oak height-growth patterns closely paralleled the regional curves of Schnur (1937). Missouri white oak trees tended to grow somewhat faster than Carmean's trees (1971) up to 50 years of age, but much slower from 50 to 80 years. Missouri black and scarlet oaks tended to grow faster in height at ages less than 50 years and slower at ages more than 50 years than trees represented by both the Schnur (1937) and Carmean (1971) regional curves.

Computation of the Confidence Intervals

The site index confidence intervals (CI) were computed from the equation:

$$CI = t \cdot s_{\bar{x}}$$

The "t" was obtained from standard tables and was based on the chosen probability level and 2, 4, 9, or 19 degrees of freedom for the 3-, 5-, 10-, and 20-tree measurements, respectively. The $s_{\bar{x}}$ was obtained from the formula:

$$s_{\frac{x}{x}} = \left[\frac{s_p^2 + s_t^2}{n} \right]^{1/2},$$

in which n = the number of trees measured (3, 5, 10, or 20), s_p^2 (plot variance) = the variance of site p indexes of trees in relatively homogeneous even-aged stands, and s_t^2 (tree variance) = the variance of the site index estimate for the specified height and age.

The s_p^2 was obtained from 77 white oak and 48 black oak 1/5-acre plots. Three trees were sectioned on each plot and their site index determined as previously described. The s_p^2 for each of the two species was then the average $\sum (SI - \overline{SI})^2 / n - 1$ of all the plots, and represented the variance of the actual site indexes in relatively uniform forest stands.

The s_t^2 was the $s_{y.x}^2$ of the site index/height regressions and represented the variance in estimated site index for given heights and ages.

The confidence intervals (tables 1 and 2) should be interpreted as *minimum* intervals that would be encountered in normal field use. The s_p^2 values were based on trees from small plots chosen for their apparent uniformity of tree growth and site index. Variation in site index over larger, less homogeneous areas would undoubtedly be greater. The confidence intervals were based on data from felled and sectioned trees from which precise height and age measurements could be made. Comparable measurements on standing trees would probably be less precise. The confidence intervals are strictly applicable only at the mean height of the trees used in each site index/height regression. The intervals increased slightly with increased deviation of height from the mean and were as much as 1/2 foot greater at height extremes for trees less than 20 years old. The increases were negligible, however, over a broad range of medium heights for trees more than 20 years old.

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BROWN SPOT NEEDLE DISEASE

biology and
control in scotch
pine plantations



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CONTENTS

Application	1
Early Detection	1
Symptoms	1
Susceptible Hosts	2
Life History	2
Control Measures	3
Documentation	7
Life History Study	7
Host Range Studies	13
Fungicide Studies	15
Literature Cited	19

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BROWN SPOT NEEDLE DISEASE--
BIOLOGY AND CONTROL IN SCOTCH PINE PLANTATIONS

Darroll D. Skilling and Thomas H. Nicholls

A P P L I C A T I O N

Christmas tree growers in the north-central States have recently experienced serious losses due to brown spot needle disease, caused by the fungus *Sairrhia acicola* (Dearn.) Siggers. Scotch pine (*Pinus sylvestris* L.) needles infected by this fungus drop prematurely, resulting in unmerchantable trees. Brown spot has been reported in Scotch pine plantations in seven States. Growers with Scotch pine plantations in these States should watch closely for brown spot infection (fig. 1).

The USDA Forest Service after extensive research has recently developed control measures for brown spot needle blight. When properly applied, these controls will eliminate the current losses from this disease.

EARLY DETECTION

Early detection and control of brown spot in Christmas tree plantations will prevent serious economic losses to growers. Generally, 2 to 3 yrs elapse before brown spot reaches epidemic status. During this time the grower can identify the problem and apply control measures. Plantation owners who suspect their trees are infected with brown spot should contact their local extension forester or forest pest management office for assistance. Positive confirmation of brown spot requires isolation and identification of the causal organ-

ism. This service is available free of charge from the following agencies:

Plant Disease Clinics, Departments of
Plant Pathology, State Universities

Plant Pest Divisions, Departments of
Natural Resources or State Departments
of Agriculture

Forest Pest Management
State and Private Forestry
USDA Forest Service
6816 Market Street
Upper Darby, PA 19082

Forest Pest Management
State and Private Forestry
USDA Forest Service
1720 Peachtree Rd., NW
Atlanta, GA 30309

SYMPTOMS

The first symptoms of brown spot infection on Scotch pine usually appear in late August. At that time yellow spots develop on the infected needles (fig. 2). These needle spots are often resin-soaked. The majority of the infected needles will be found on the lower branches of the tree, especially on the north side. Infected needles of all ages start dying from the

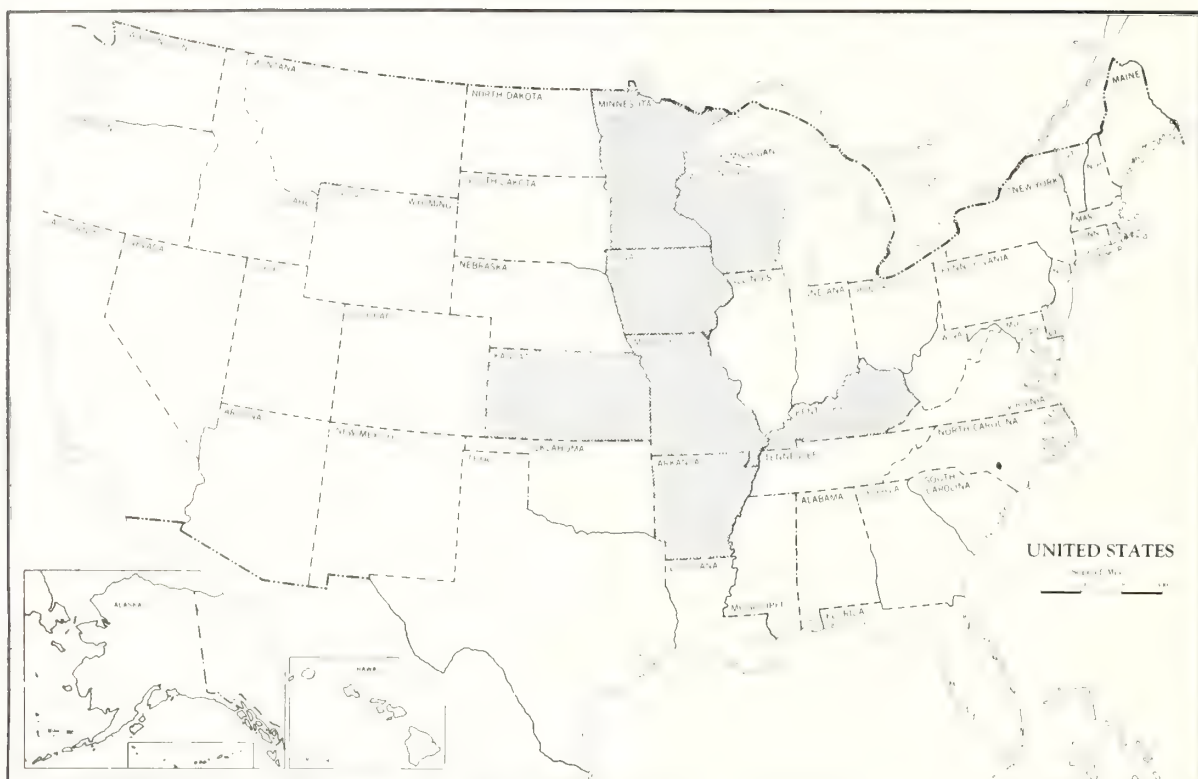


Figure 1.--Brown spot has been reported in Scotch pine Christmas tree plantations in the seven shaded States. Growers in these States should be alert for brown spot infection in their plantations.

tips back until entire needles turn brown and fall off during October and November (fig. 3). In lightly infected plantations, only the 2- and 3-yr-old needles are lost. This should not be confused with the normal fall shedding of 3-yr-old needles by Scotch pine. As infection becomes more severe, the current-year needles also are infected and are shed during the fall. The result is mostly bare branches and a totally unsalable Christmas tree. In severe cases branches are killed by the disease, but usually the buds of infected trees remain healthy and produce new foliage the following spring. This new foliage also becomes infected, continuing the disease cycle.

SUSCEPTIBLE HOSTS

Although brown spot is able to infect at least 28 species of pine, it formerly only caused economic losses to loblolly pine in the southern United States (Siggers 1944).

With the planting of large areas to Scotch pine for Christmas trees, brown spot now causes serious losses to this species as well. Other Christmas tree species that have been infected by the brown spot fungus in field-inoculation tests include eastern white, Austrian, red, ponderosa, jack, and Virginia pines.

LIFE HISTORY

Two types of spores are produced by the brown spot fungus on loblolly pine in the southern United States. The windblown ascospores provide long-distance spread while the sticky, rainsplash-disseminated conidia are responsible for tree-to-tree spread and for disease buildup on infected trees. In the north-central area, the life cycle on Scotch pine is slightly different. No evidence of windblown ascospores has been found. Evidently, all infection is due to the conidial stage.

These conidia are moved about by rain and by other agents such as man or other animals. The conidia infect Scotch pine needles from June to September. The major infection period, however, is in late June and early July. Rainfall is the primary factor for conidia dissemination. Moisture is necessary on the needle surface for germination to occur. New fruiting bodies with mature conidia are found on infected needles in late August (fig. 4). Although many conidia are released from these fruiting bodies in September, little infection seems to take place at this time. The major infection results from overwintering fruiting bodies that release conidia in early summer as the new needles are developing.

CONTROL MEASURES

Chemical

To prevent infection of new foliage, a fungicide must be applied in plantations where brown spot occurs. No natural controls are known for susceptible Scotch pine varieties. The disease may subside during dry years but will increase again when moisture conditions return to normal. Prompt control measures will maintain tree vigor and minimize losses from other insect and disease problems.

When to Spray

Applying fungicides at the proper time is essential for satisfactory brown spot control. The fungicides must be applied before needle infection by the fungus spores. Once infection takes place treatment is not effective. The first spray should be applied when the new needles are about half grown. In the north-central region this is about mid-June. In severely infected plantations or during unusually wet years, a second spray should be applied 3 to 4 weeks later.

What to Use

Two fungicides are currently recommended for use against brown spot in Scotch pine plantations--Bordeaux mixture and chlorothalonil. Both are registered for this purpose.

Christmas tree growers in Wisconsin have been spraying with Bordeaux mixture for 3 yrs and have found it to be safe and effective. It also remains active on the needle surface longer than many other fungicides. Bordeaux mixture, however, has some disadvantages.

The material is difficult and time-consuming to prepare due to its poor water solubility. It is also alkaline and is not compatible with many insecticides. Because of these problems many growers prefer to use other fungicides.

Chlorothalonil (sold under such trade names¹ as Bravo and Daconil) is also effective for control of brown spot. This fungicide has only recently been registered for this purpose. Although more expensive than Bordeaux mixture, it is easily prepared and is not corrosive to equipment. It is also very effective against *Lophodermium* needlecast, another serious disease of Scotch pine plantations. Because of its advantages over Bordeaux mixture, the use of chlorothalonil for brown spot control probably will increase.

How to mix.--Chlorothalonil is relatively easy to prepare. The wettable powder is added to the water in the spray tank and agitated. No spreader-sticker is necessary. The recommended rate is 2.5 lb/100 gal of water for hydraulic sprayers and 6 lb/100 gal of water for mist blowers.

To use Bordeaux mixture, a few additional steps are necessary. Bordeaux is a mixture of copper sulfate (instant powder, blue vitriol) and hydrated lime in water. For control of brown spot with hydraulic sprayers, a mixture of 8 lb copper sulfate, 8 lb hydrated lime, and 100 gal of water is recommended. Growers normally use a 24-24-100 mixture when using mist blowers. In preparing the mixture, the solutions of copper sulfate and lime should be made separately. Using 8-8-100 formula, 8 lb of copper sulfate are dissolved in 50 gal of water and 8 lb of hydrated lime are dissolved in another 50 gal of water. When the mixture is to be used, pour the two solutions together through a copper sieve (about 20 meshes to the inch) to exclude small particles that may plug spray nozzles. Constant agitation is necessary to prevent the material from settling to the tank bottom. Because Bordeaux mixture loses some of its effectiveness within a few hours after preparation, material remaining in the sprayer at the end of the day should be discarded according to approved pesticide disposal methods. Bordeaux mixture is very corrosive to most metal equipment. Fiberglass

¹Manufactured by FMC Corp., P.O. Box 1000, Philadelphia, Pa. 19106.
USDA Forest Service.



Figure 2.--Needle spots caused by the brown spot fungus, *Scirrhia acicola*. In the North Central States these spots appear in late August.

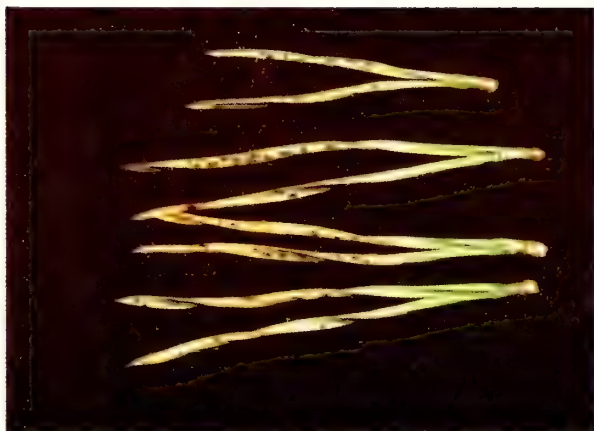


Figure 4.--The brown spot fruiting bodies are visible on infected needles by late August. Major infection takes place the following late June or July by means of rainsplash-disseminated conidia.



Figure 3.--Brown spot infection is more severe on the lower portion of the tree, especially on the north side where moisture conditions are most conducive to infection.



Figure 5.--Hydraulic sprayers such as this straddle type are very effective for applying fungicides to control foliage diseases in Christmas tree plantations.

Figure 6.--Mist blowers in general are more economical for Christmas tree spray operations than the hydraulic type. The large blowers develop windspeeds of 95 mi/h and can spray up to 20 rows of trees if the road system permits spraying from both sides.



or stainless steel tanks are recommended and all spray equipment must be washed and rinsed thoroughly at the end of the day.

Application equipment.--Most growers apply fungicides with hydraulic sprayers or mist blowers. To be effective, the hydraulic sprayer must have a working pressure sufficient to completely moisten all tree foliage (fig. 5). Hydraulic sprayers use about 100 gal of fungicide/acre. In general, hydraulic sprayers cover less area per hour than air-blast mist blowers. The latter can spray up to 20 rows of trees if the road system permits spraying the trees from both sides (fig. 6). A large mist blower will develop windspeeds of 95 mi/h and cover about 8 acres of plantation/hr. Most mist blowers use about 40 gal of fungicide/acre, which is considerably less than the hydraulic sprayers use and explains the use of a more concentrated mixture. The new low-volume mist blowers use only about 20 gal/acre. Here the concentration of Bordeaux mixture is 12-12-20.

Weather

To be effective, fungicides should be allowed to dry on the needles; therefore, they should not be applied during rain. Subsequent rainfall is not as detrimental. Foliage should be sprayed when the air is calm to obtain even coverage.

Safety Precautions

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels. Store pesticides in original containers under lock and key--out of the reach of children and animals--and away from food and feed.^{2/}

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects

are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first-aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

Cultural Control

In addition to chemical control, the following cultural practices will either prevent brown spot infection or reduce its severity.

Plant only healthy nursery stock. It is far easier to keep disease out of a plantation than to control it once it is established. Although State nursery inspection is improving, there have been many cases in recent years in which diseased stock was shipped from nurseries. If stock has turned brown or contains infection spots on the foliage, the trees should be examined by a plant pathologist before planting. If brown spot or other foliage diseases are present, the trees should be returned to the nursery.

Plant resistant varieties. The short-needed Scotch pine are more susceptible to the brown spot fungus than the long-needed varieties. The varieties "Spanish" and "French-green" are especially susceptible. To avoid catastrophic losses, a grower should avoid planting all his land in one species or one variety.

²Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State extension specialist to be sure the intended use is still registered.

Avoid planting Scotch pine seedlings next to older Scotch pine windbreaks. Trees in windbreaks frequently serve as a reservoir for the brown spot fungus as well as for other diseases and insects. If planting near windbreaks is unavoidable, the windbreak trees should be cut and burned the year before planting the new stand. Stumps should be removed or treated with a registered insecticide for weevil control.

Cut and remove small pockets (1 to 5 trees) of brown-spot-infected trees in a plantation. All remaining trees within 30 ft of the infected area should be sprayed with a fungicide at the proper time. A backpack mist blower works well for this type of operation. If there are several pockets of infected trees, the whole plantation should be sprayed as outlined earlier.

Avoid leaving live branches on stumps when harvesting trees, especially in infected plantations. These lower branches are

especially susceptible to foliage diseases such as brown spot. Needles on these lower branches serve to perpetuate the brown spot fungus.

Remove infected trees as soon as they have been cut. Brown spot spores are produced throughout the growing season. Unless infected trees cut during the spring are removed, they will produce spores into the fall.

Do not shear infected plantations during wet weather. Brown spot spores ooze out of fruiting bodies when the foliage is wet and can easily be spread from tree to tree on shearing tools or workers' clothing. Healthy plantations should be sheared first to avoid carrying spores into them from diseased plantations. If this is not practical, the shearing tools should be sterilized with denatured alcohol for 3 to 5 min after shearing infected plantations.

DOCUMENTATION

Brown spot disease has recently caused damage in seven north-central States. These States grow 31 percent of the Nation's Christmas trees at a market value of more than \$70 million. Wisconsin was hardest hit of these States; from 1967 through 1970, several hundred thousand Scotch pines were unsalable because of brown spot infection (Skilling and Nicholls 1972, Prey and Morse 1971).

After discovery of brown spot needle disease in Wisconsin, research studies were begun to develop practical control measures for this serious disease. The research involved (1) studying the life history of the causal organism, *S. acicola*, (2) host range studies, and (3) fungicide evaluation for disease control.

LIFE HISTORY STUDY

The primary objective of this study was to determine what influence the temperate Lake States environment had upon the biology and life history of the brown spot fungus and at what points in its life cycle it was most vulnerable to control. Specifically, we investigated (1) how climate affected the biology of the fungus, (2) how the fungus overwinters, (3) the seasonal development of host and parasite, (4) how spores are disseminated, and (5) when infection takes place.

Methods

Climate and Phenology

Disease development is affected by climatic conditions. To obtain a measure of the various conditions, weather stations were maintained in several areas in Wisconsin and Minnesota during 1970 and 1971. Each station consisted of a weather shelter containing a temperature-relative humidity, 7-day recording hygrothermograph, and a rain gage (fig. 7) which were serviced at weekly intervals. The resulting weather data were correlated with the seasonal development of the disease and the host.

At each weather station phenological records of parasite and host development were

made at weekly intervals throughout the growing season (April to October) and at lesser intervals during the other months. These data provided a graphic summary of new needle growth, timing of spore discharge and dissemination, infection periods, and symptom development.

Spore Release and Dissemination

1970.--To trap brown spot spores, six vaseline-coated microscope slides were placed in brown-spot-infected Scotch pine Christmas tree plantations near Black River Falls, Wild Rose, and Boscobel, Wisconsin, and near Hastings, Minnesota (fig 8). Two of the slides were placed directly under infected Scotch pine trees, two were placed in the upper crowns, and two were placed in the open short distances from infected trees. These slides were changed at weekly intervals to provide information on short-distance dissemination of spores. To determine the long-distance dissemination of spores, slides were placed from 5 to 3,520 yd in various directions from infected trees. Slides were also placed in an infected 35-yr-old Scotch pine windbreak that was adjacent to a Scotch pine Christmas tree plantation near Brodhead, Wisconsin. These slides were changed at irregular intervals throughout 1970.

The duration of spore discharge from cut brown-spot-infected Scotch pine Christmas trees was determined at Black River Falls by placing the trees on top of a wire frame located 4 ft above the ground. The infected trees were left on the frame from May until the end of September 1970 to see how long cut trees produce brown spot conidia. To measure this factor, two vaseline slides were placed under the infected trees. The slides were periodically changed and the spores counted. Before the frame was put in place, susceptible pine seedlings were planted to serve as indicators of infection.

1971.--Similar procedures were followed in 1971. Some of the slide locations were changed to obtain more detailed information on short-distance spread of spores between closely planted Christmas trees. Six slides were also used to determine the effect of fungicides on spore production.

The study areas were the same as in 1970 except the Hastings, Minnesota, study area

was replaced by one near Trempealeau, Wisconsin. As in 1970, six slides were used at each plantation. Two were placed under infected trees, but the other four were placed at the cardinal directions 1 to 54 in. from infected trees. Of the six slides used in the heavily infected Trempealeau plantation, two were placed under unsprayed trees, two under trees sprayed with Du-ter (triphenyltin hydroxide), and two under trees sprayed with Fundilan (a mixture of chlorothalonil and cycloheximide). Some slides were left out from November through April to see if any spores were released during the winter months.

Field observations indicated that as Scotch pine needles grow older they are more resistant to brown spot infection. To verify this observation, potted greenhouse-grown Spanish Scotch pine seedlings were exposed to brown spot spores by placing them under heavily infected Scotch pine Christmas trees for various time intervals throughout the growing season. The potted seedlings were then removed to a greenhouse and observed for symptom development on the current-year needles.

Results

Climate and Phenology

The disease symptoms and life history of the fungus described earlier in this paper were based on the phenological development of the brown spot disease on Scotch pine (table 1).

Brown spot pycnidia were present throughout the year although more abundant at certain times than others. Rainfall and low temperatures were the most critical weather factors influencing spore release. Spores were released throughout the growing season but only during rainy weather. Spore release decreased rapidly or stopped as temperatures approached 2° C (35° F).

Spore Release and Dissemination

Spore release throughout the growing season was correlated with rainfall and current-year needle growth (figs. 9 and 10). Generally, two spore peaks occurred, one in June and one in late August and September as seen below:

Spore trapping period ³	Conidia trapped (Number)
June 3 - June 5, 1970	17
June 5 - June 29, 1970	2,232
June 29 - July 21, 1970	446
July 21 - Aug. 21, 1970	161
Aug. 21 - Sept. 30, 1970	858
Sept. 30 - Oct. 30, 1970	282
Oct. 30 - Dec. 1, 1970	22
Dec. 1, 1970 - May 5, 1971	0

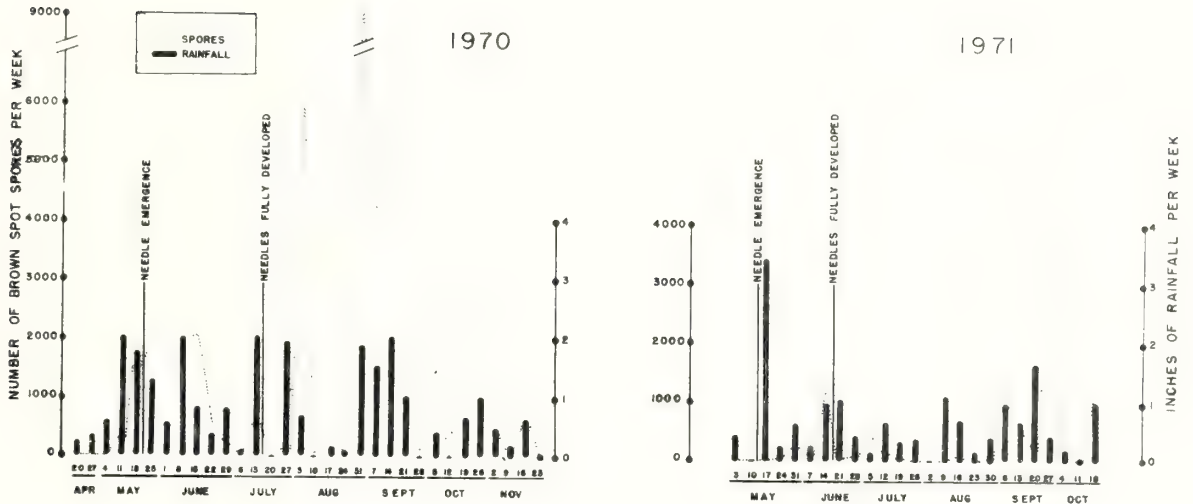
³Number of brown spot conidia collected in an infected 35-yr-old Scotch pine windbreak near Brodhead, Wis., based on two spore traps for each period.

Table 1.--Average dates of needle growth and brown spot fungus development on current-year Scotch pine needles in Wisconsin and Minnesota, 1970 and 1971

Location ¹	: : Start : of new: : needle:	: Current- : year needle : growth : complete :	: Appearance : of needle spots : on current-year : needles	: Appearance of brown- : ing and fruiting : bodies on current- : year needles	: Dropping : of current-year : needles began
Brodhead, Wis.	5/17	7/15	8/13	8/24	9/17
Boscobel, Wis.	5/17	6/28	8/2	8/13	8/31
Trempealeau, Wis.	5/10	7/12	8/16	8/9	8/23
Wild Rose, Wis.	5/31	7/23	8/17	9/7	9/24
Black River Falls, Wis.	5/21	8/10	8/9	8/16	9/17
Hastings, Minn.	6/7	8/20	8/18	8/31	9/29

¹Locations listed from the southern to northern parts of the State.

BOSCOBEL, WIS.



WILD ROSE, WIS.

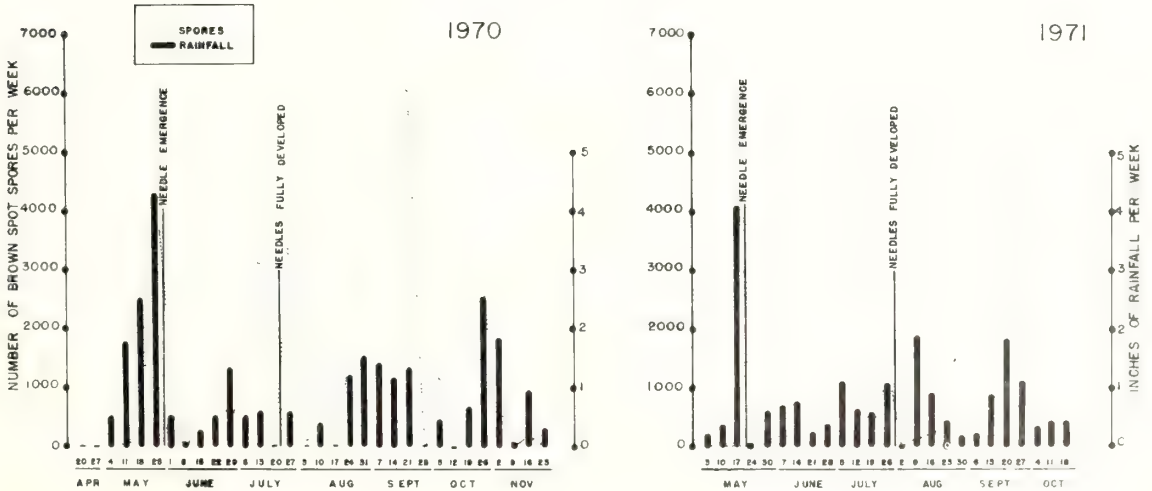


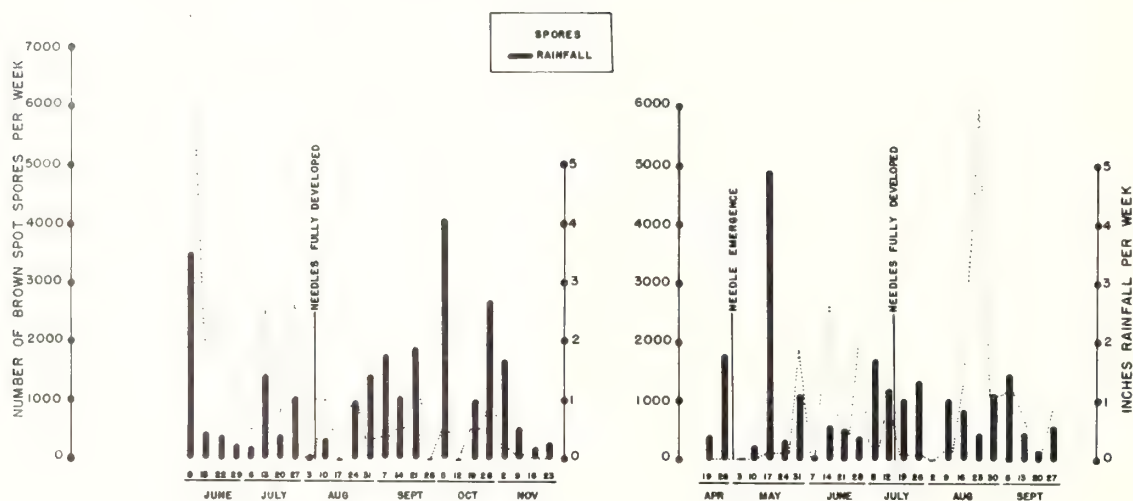
Figure 9.--Weekly rainfall, and numbers of brown spot conidia trapped weekly in infected Scotch pine plantations at Boscobel and Wild Rose, Wisconsin. Spore number equals the total number of spores counted on three sample strips taken on each of six spore trap slides in each plantation.

HASTINGS, MINN.

1970

TREMPEALEAU, WIS.

1971



BLACK RIVER FALLS, WIS.

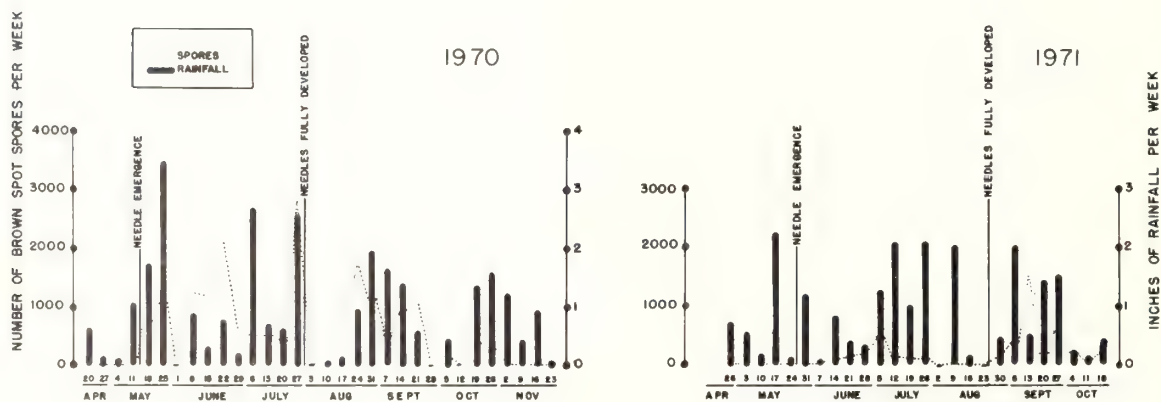


Figure 10.--Weekly rainfall, and numbers of brown spot conidia trapped weekly in infected Scotch pine plantations at Hastings, Minnesota, and Black River Falls and Trempealeau, Wisconsin. Spore numbers equals the total number of spores counted on three sample strips taken on each of six spore trap slides in each plantation.

Spores released during the first peak are the most important in terms of infecting the new needles. A fungicide must be applied before this peak to prevent infection. Young, growing Scotch pine needles are more susceptible to infection than mature needles. Despite the abundant spore release during late August and September, little infection occurs because the needles are more resistant. Heavy infection occurred on trees exposed between June 26 and July 24, little infection occurred on trees exposed after July 24, and no infection occurred on trees exposed after September 6 (table 2).

Table 2.--Needle infection of Spanish Scotch pine seedlings placed under infected Scotch pine Christmas trees at Hastings, Minn. and Wild Rose, Wis.¹

HASTINGS, MINNESOTA			
Period subjected to spore casts	Disease rating ²	Amount of	
1972		rainfall	
		Inches	
5/15 to 5/30	0	1.33	
6/9 to 6/26	0.8	2.00	
6/26 to 7/10	2.7	1.38	
7/10 to 7/24	2.3	4.29	
7/24 to 8/7	.3	1.68	
8/7 to 8/18	.3	.30	
8/18 to 9/6	.2	2.89	
9/6 to 9/18	0	.78	
9/18 to 10/16	0	3.72	
WILD ROSE, WISCONSIN			
6/6 to 9/6	4.0	9.53	
9/6 to 10/4	0	2.00	

¹Three to seven seedlings were placed under the infected tree, left for the indicated period of time, and returned to a greenhouse for symptom development. Symptom readings were made on December 14, 1972.

²Based on a scale of 0 to 4: 0=no infection, 1=1 to 25 percent of needles infected, 2=26 to 50 percent of needles infected, 3=51 to 75 percent of needles infected, and 4=76 to 100 percent of needles infected.

Spore release was dependent on the occurrence of rainfall (figs. 9 and 10). Despite adequate rainfall, few spores were released in April and November, probably due to low temperatures. No spores were trapped from December through the end of April.

Brown spot spores were collected on 750 slides exposed at 24 locations within and some distance from brown-spot-infected Scotch pine trees in 1970. Most spores were

trapped in the lower crowns of trees while only a few spores were trapped 1 to 10 ft from infected trees (table 3). This resulted from rainsplash dissemination of spores and the greater number of fruiting bodies present in the lower crowns.

As in 1970, the 1971 data show that the majority of spores were trapped within or under infected trees (table 4). Significant fewer spores were trapped from 1 to 54 in. away from infected trees. However, the 1970 and 1971 data show that enough rainsplash spores are disseminated short distances to spread the fungus between closely planted Christmas trees.

Means for long-distance dissemination of the fungus has not been determined in the North. Despite the exposure of more than 1,300 spore trap slides during 1970 and 1971, no brown spot ascospores were collected. Numerous infected needles were also examined at different times of the year, but no perfect-stage fruiting bodies were found. This is in contrast to the southern United States where both conidia and ascospores are common on longleaf pine (Kais 1971). The most northern record of the perfect stage was made near Ashland, Missouri, on ponderosa pine (*Pinus ponderosa* L.) (Luttrell 1949)

Evidence was found for two other possible means of long-distance spore dissemination: insect and man. Insect dissemination of brown spot conidia may be possible because the spores are sticky and numerous insects inhabit the plantations. During June 1970, two scales of a lepidopterous insect were observed on a spore trap 10 ft from the nearest infected tree. Twenty-five brown spot conidia were attached to these scales. If spores such as this were to come in contact with susceptible tissue, infection might result. Spores also may be spread by shearing. If infected trees are sheared while the foliage is wet, the sticky spores can be carried on shearing tools. This was determined by applying the sticky side of cellophane tape to the blades of shearing knives that had been used to shear wet brown-spot-infected trees and then placing this tape on glass slides. Microscopic examination revealed hundreds of brown spot conidia on the tapes. This suggests conidia are spread from one tree to another or within the same tree during shearing, which could be a significant means of spore dissemination within Christmas tree plantations.

Table 3.--Total number of brown spot conidia collected by spore traps placed at random locations within and near infected Scotch pine trees

Study area	Spore trapping period (1970)	Total slides exposed	Location of spore traps	Conidia trapped ¹	Total rainfall during trapping period
		Number		Number	Inches
Black River Falls, Wis.	Apr. 20	66	Upper crown	7,786	28.13
	to	66	Under tree	10,904	
	Nov. 30	33	1 ft from tree	65	
		33	5 ft from tree	14	
Boscobel, Wis.	Apr. 20	66	Upper crown	23,457	25.11
	to	66	Under tree	28,403	
	Nov. 30	33	1 ft from tree	470	
		33	5 ft from tree	58	
Wild Rose, Wis.	Apr. 20	66	Upper crown	15,895	26.20
	to	66	Under tree	30,114	
	Nov. 30	33	1 ft from tree	245	
		33	5 ft from tree	15	
Hastings, Minn.	June 8	52	Upper crown	2,845	24.58
	to	52	Under tree	22,888	
	Nov. 30	26	2 ft from tree	19	
		26	10 ft from tree	3	

¹All brown spot conidia were counted on three random vertical strips across the width of each slide using a microscope at 430X.

Table 4.--Total number of brown spot conidia trapped on 25 slides placed under and at various distances from infected Scotch pine trees

Study area	Distance and location from crown edge of infected trees	Conidia trapped ²	Total rainfall
	Inches	Number	Inches
Black River Falls, Wis.	10 north	42	21.37
	11 east	10	
	8 south	8	
	6 west	73	
	0 under tree	1,891	
	0 under tree	2,371	
Wild Rose, Wis.	8 north	1,803	17.82
	7 east	3,233	
	5 south	3,446	
	1 west	3,552	
	0 under tree	18,342	
	0 under tree	21,279	
Boscobel, Wis.	54 north	5	15.54
	27 east	18	
	54 south	13	
	42 west	31	
	0 under tree	3,063	
	0 under tree	6,583	

¹A different slide was exposed during each of 25, 7-day time intervals between May 3 and October 25, 1971, at each location.

²All brown spot conidia were counted on three random vertical strips across the width of each slide using a microscope at 430X.

Brown-spot-infected Scotch pine Christmas trees cut in May 1970 released spores from May 20 to September 28 as seen below:

Spore trapping period ⁴	Conidia trapped (Number)
May 20 - May 30	1,927
May 30 - June 7	1,152
June 7 - June 18	5,084
June 18 - July 16	7,617
July 16 - July 23	573
July 23 - Aug. 7	2,313
Aug. 7 - Aug. 22	392
Aug. 22 - Sept. 10	729
Sept. 10 - Sept. 28	254
Sept. 28 - Oct. 28	0
Oct. 28 - Nov. 30	0

Susceptible seedlings grown under these cut trees became infected. Therefore, infected trees that are cut should be removed from the plantation or destroyed. An evaluation of inoculum remaining in a plantation after merchantable and unmerchantable materials had been cut revealed that branches with infected needles remained on 86 percent of the stumps (N=50). Many of these branches were in contact with adjacent uncut trees and presumably could cause infection of these trees. Therefore, all infected trees should be cut below the bottom whorl of branches to reduce this potentially important source of inoculum.

The incidence of trapped brown spot spores under infected Scotch pine was dramatically reduced by fungicide treatment (table 5). Du-ter and Fundilan fungicide sprays protected new foliage while the new foliage of unsprayed trees became infected. The newly infected foliage produced fruiting bodies and released thousands of spores in the latter half of the growing season. The fungicide-treated trees produced very few spores by comparison.

The decrease in spores from 1970 to 1971 for the Boscobel area was not due to fungicide control (fig. 9). Instead, it was due to extremely heavy infection in previous years. As a result, by 1971 many trees were almost devoid of foliage and some trees actually lost all their needles and died. Because of this lack of infected foliage, there were

⁴Number of conidia collected under recently cut brown-spot-infected Scotch pine Christmas trees. Two vaseline-covered slides were exposed during each period.

Table 5.--Effect of fungicide treatment on spore discharge

Spore trapping period	Treatment	Conidia trapped ¹
Number		
Apr. 19 - June 28	Unsprayed	2,411
	Du-ter ²	1,146
	Fundilan ³	1,721
June 28 - Aug. 16	Unsprayed	2,247
	Du-ter	421
	Fundilan	82
Aug. 16 - Oct. 4	Unsprayed	9,381
	Du-ter	478
	Fundilan	75

¹Reduction in spore discharge due to prevention of new infection and mechanical reduction of inoculum by air blast at time of spraying.

²Trees sprayed on June 23, 1971, with Du-ter (12 oz commercial/100 gal water).

³Trees sprayed on June 23, 1971, with Fundilan (96 oz commercial/100 gal water).

fewer fruiting bodies present so the number of spores released in 1971 decreased sharply.

HOST RANGE STUDIES

Methods

The potential impact of the brown spot disease on conifer species in the Lake States was determined by field inoculation experiments. Red pine (*Pinus resinosa* Ait.), eastern white pine (*P. strobus* L.), jack pine (*P. banksiana* Lamb.), Austrian pine (*P. nigra* Arnold), white spruce (*Picea glauca* (Moench) Voss), and four varieties of Scotch pine were exposed to natural infection by planting under heavily infected Scotch pine Christmas trees or windbreaks in five different areas in Wisconsin and Minnesota between 1970 and 1972. Longleaf pine (*Pinus palustris* Mill.) was also tested for susceptibility because it is the classical host for the brown spot fungus in the southern United States.

These trees were examined for symptoms of brown spot infection each fall. The amount of infection present in current-year and 1-yr-old needles was recorded according to the following classification system:

0=no infection;

T=less than 1 percent of needles infected;

1=1 to 25 percent of needles infected;

2=26 to 50 percent of needles infected;

3=51 to 75 percent of needles infected; and

4=76 to 100 percent of needles infected.

Isolations were made periodically from infected needles to confirm the presence of the brown spot fungus.

Results

Spanish and French-green Scotch pine varieties were highly susceptible to brown spot, as was Austrian pine (table 6, fig. 11). The long-needled Austrian Hills and German varieties of Scotch pine varied between moderately susceptible to moderately resistant, with the German variety being the most resistant to brown spot.

Red pine, which was moderately susceptible, is recognized as a new host to brown spot infection (Nicholls and Hudler 1972) (fig. 11). Older red pine needles were more susceptible to infection than were current-year needles (table 6). In addition, red pine appears to gain resistance as it grows older. However, brown spot could cause serious damage to red pine seedlings grown in nurseries or to seedlings out-planted among or adjacent to brown-spot-infected Scotch pine Christmas tree plantations or windbreaks.

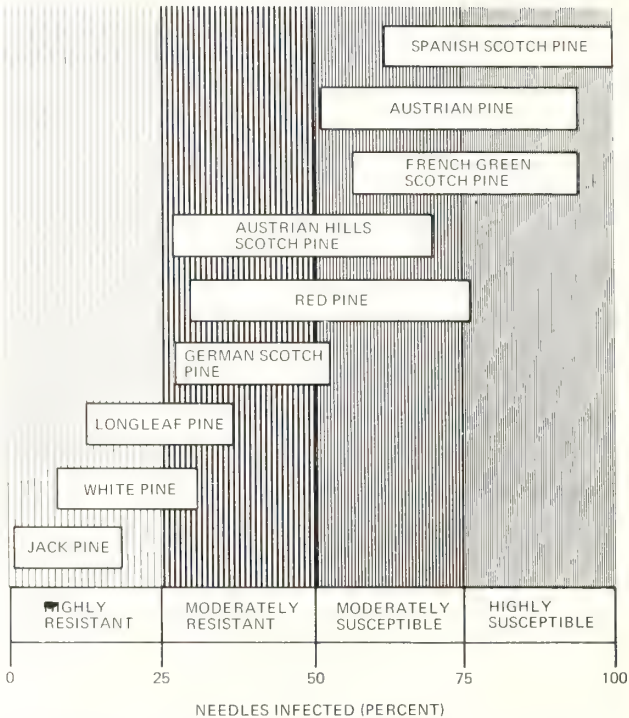


Figure 11.--Range of conifer susceptibility or resistance to the brown spot fungus.

Table 6.--Average degree of brown spot infection of conifer seedlings planted under brown-spot-infected Scotch pine trees located near Black River Falls, Wild Rose, and Brodhead, Wis., and Hastings, Minn.

Species	Month and year of evaluation											
	September 1970				September 1971				October 1972			
	1969 needles		1970 needles		1970 needles		1971 needles		1971 needles		1972 needles	
	Degree:	Trees	Degree:	Trees	Degree:	Trees	Degree:	Trees	Degree:	Trees	Degree:	Trees
	inf. ¹	Number	inf.	Number	inf.	Number	inf.	Number	inf.	Number	inf.	Number
Spanish Scotch pine	3	119	2	158	4	73	3	150	4	9	4	58
French-green Scotch pine	2	96	2	149	4	40	3	138	3	22	3	113
Austrian Hills Scotch pine	2	109	1	154	3	95	2	151	1	27	1	140
German Scotch pine	1	104	1	143	2	123	1	142	1	40	1	118
Austrian pine	--	--	--	--	--	--	--	--	4	117	2	110
Red pine	1	145	0	142	3	123	T	133	3	621	T	619
White pine	T	108	0	131	1	85	T	127	1	73	1	118
Jack pine	T	131	0	130	1	125	T	129	T	98	0	103
Longleaf pine	--	--	--	--	--	--	1	82	--	--	1	81
White spruce	--	--	--	--	--	--	--	--	T	89	0	91

¹Infection code: 0=no infection; T=less than 1 percent of needles infected; 1=1 to 25 percent of needles infected; 2=26 to 50 percent of needles infected; 3=51 to 75 percent of needles infected; 4=76 to 100 percent of needles infected.

Of the three native Lake States pine species, red pine was the most susceptible to brown spot, white pine was moderately to highly resistant, and jack pine was highly resistant (fig. 11). Only a trace of infection was found on white spruce.

High seedling mortality (20 to 83 percent) occurred in the short-needled Spanish and French-green Scotch pine varieties after 3 successive years of heavy defoliation caused by brown spot. There was very little mortality (3 to 5 percent) in the long-needled German and Austrian Hills Scotch pine varieties. These results agree very well with the average degree of foliage infection for these varieties (table 6). This again illustrates the high resistance of long-needled Scotch pine varieties to brown spot.

Although longleaf pine became infected during the study, it was still quite resistant. Evidence indicates that there are races of *S. acicola* and that the northern race is not as pathogenic on longleaf pine as the southern race (Kais 1972). This may explain the resistance shown by longleaf pine in this study.

FUNGICIDE STUDIES

Laboratory Tests

Fifteen fungicides were screened in the laboratory for activity against the brown spot fungus using the modified paper disk bioassay method (Sharvelle and Pelletier 1956). Different amounts of fungicides dissolved in acetone were applied to small filter paper disks (12.7 mm). Each disk was inoculated with 0.024 ml of a suspension of brown spot conidia. The inoculated disks were placed in petri dishes with potato dextrose agar at 20° C for 5 days. The relative density of mycelial growth was then recorded. If no mycelium was observed after 10 days, the disk was removed to a different spot on the agar and turned over to determine whether the test material was fungicidal or fungistatic to *S. acicola*. The fungicides tested were:

1. Manganous ethylenebis [dithiocarbamate] (maneb) (Manzate 70W).
2. Bordeaux mixture (8-8-100).
3. *N*-[(trichloromethyl)thio]phthalimide (folpet) (Phaltan 50W).
4. *Cis-N*-(1,1,2,2-Tetrachloroethylthio)-4-cyclohexene-1,2-dicarboximide (captafol) (Difolatan 4F).

5. Zinc dimethyl-dithiocarbamate (ziram) (Zerlate 76W).

6. Methyl 1-(butyl carbamoyl)-2-benzimidazole carbamate (benomyl) (Benlate 50W).

7. Bis(dimethylthiocarbamoyl) disulfide (thiram) (Thylate 99W).

8. Tetrachloroisophthalonitrile (chlorothalonil) (Bravo W75).

9. A mixture of chlorothalonil plus 0.025 percent cycloheximide (Fundilan 75W).

10. Cuprous oxide.

11. 2-(thiocyanomethylthio) benzothiazole (TCMTB 30W).

12. 2-(4-thiazolyl) benzimidazole (Tobaz 25W).

13. Triphenyltin hydroxide (Du-ter 47.5W).

14. Alpha-(2,4-dichlorophenyl)-alpha-phenyl-5-pyrimidine methanol (Triarimol, EL-273).

15. 1,2-Bis(3-methoxy carbonyl-2-thioureido) benzene (Topsin 70W).

16. 3-(3,5-dichlorophenyl)-5,5-dimethyl oxazolidine-dione-2,4 (dichlozoline) (Sclex 30W).

17. Piperazine-1,4-diyl-bis-1-(2,2,2-trichloroethyl) formamide (Cela W524).

Bordeaux mixture, Du-ter, Ziram, and Benomyl were strongly fungicidal to the brown spot organism and were selected for preliminary field evaluation. Chlorothalonil and Fundilan were tested later and found to be fungicidal to *S. acicola* and were added to the field test.

Field Tests and Results

Wautoma Area

The study area near Wautoma, Wisconsin, was a 10-yr-old Christmas tree plantation that contained 6-ft-tall French-green Scotch pine heavily infected with the brown spot fungus. All fungicides were applied with a backpack mist blower at the rate of 1 pt/tree (fig. 12).

1970.--Fungicides tested were Bordeaux mixture (8-8-100), Du-ter (12 oz commercial/100 gal water), benomyl (12 oz/100 gal water), and ziram (96 oz/100 gal water). DuPont surfactant F was added to the benomyl, and DuPont spreader-sticker was added to the ziram.

Four different spray schedules were tested with each fungicide: (1) trees sprayed on May 20 only; (2) trees sprayed on June 25 only; (3) trees sprayed on May 20 and June 25; and (4) trees sprayed on May 20, June 25, and August 18.

Each treatment was applied to a row of 10 trees in each of 3 replications in a modified randomized block design. Each row of sprayed trees was separated from other treated rows by a buffer row of unsprayed trees. Ten unsprayed trees were included in each replication as a control.

Treatments were evaluated on September 21, 1970, and again on May 26, 1971. Each tree was examined for brown spot symptoms and was assigned a disease rating. Only 1970 needles were rated. The rating system was:

- 0=no infected needles present;
- 1=1 or 2 branches with infected needles;
- 2=several branches with infected needles; and
- 3=tree heavily infected (over 25 percent of branches with infected needles).

Trees rated 0 or 1 were classified as merchantable Christmas trees.

Evaluations made in fall 1970 and spring 1971 showed that all fungicides tested gave excellent control of brown spot on trees sprayed in June, May-June, or May-June-August (figs. 13 and 14). The May-only treatment was not effective because the new needles had not emerged from the needle sheath at time of spraying. There was no evidence of disease eradication by any of the test fungicides when applied in May only. The June-only spray was the most economical. No evidence of additional disease control resulted from the August spray. Although spore-dissemination studies showed spores being cast during late summer, there was no evidence of increased brown spot symptoms between the fall and spring evaluations.

1971.--The same fungicides and concentrations were used but the spray schedules were adjusted on the basis of the 1970 test results. The spray schedules were: (1) trees sprayed on June 25 only; (2) trees sprayed on August 12 only; and (3) trees sprayed on June 25 and August 12. The trees were evaluated for brown spot symptoms on October 6, 1971, using the same rating system used in 1970.

The 1971 results were similar to those from 1970. All fungicides were effective using the June 25 spray. The August-only spray was not effective because infection took place before fungicide use. There was a rapid buildup of brown spot infections on the August-sprayed trees. The inoculum for

this probably came in part from the unsprayed, heavily infected trees on each side of the test row.

Trempealeau Area

In 1971 a new brown spot fungicide test was installed in a heavily infected 11-yr-old Scotch pine plantation near Trempealeau, Wisconsin. The stand was a mixture of short-needled varieties, with Spanish and French-green predominating. All fungicides were again applied with a backpack mist blower at the rate of 1 pt fungicide/tree.

Four fungicides were used in the Trempealeau test: Bordeaux mixture (8-8-100), Du-ter (12 oz commercial/100 gal water), Fundilan (96 oz/100 gal water), and ziram (96 oz/100 gal water). DuPont spreader-sticker was again added to the ziram.

Spray schedules were: (1) trees sprayed June 23 only; and (2) trees sprayed June 23 and August 10.

Each treatment was applied to a 10-tree row in each of 3 replications. Treated rows were separated by a buffer row of unsprayed trees. Thirty trees were included in each replication as a control. Treatments were evaluated on October 5, 1971, with the same rating system used at Wautoma.

Fundilan was the only fungicide that gave satisfactory control under the extreme infection hazard present in this plantation (table 7). Again, the June-only spray was about equal in effectiveness to the June and August spray.

Pilot Test

In 1972 a pilot test of fungicides was installed in Christmas tree plantations near Black River Falls and Poy Sippi, Wisconsin, using large air-blast mist blowers. Both plantations were Scotch pine, variety unknown, 4 to 8 ft tall.

The Black River Falls plantation was sprayed on June 14, 1972, with Bordeaux mixture (8-8-100) and Bravo W75 at 96 oz/100 gal water. The Bordeaux mixture-treated area was 1.5 acres, the Bravo area was 0.4 acre, and the unsprayed area was 0.9 acre. On October 10, 1972, 100 trees in each area were selected at random and evaluated using the same rating system as in prior studies. The



Figure 7.--Weather stations, located in Christmas tree plantations, were used to correlate weather with infection periods and with seasonal development of the brown spot fungus.



Figure 8.--Vaseline-coated microscope slide used to collect conidia of the brown spot fungus.



Figure 12.--Test fungicides were applied with a backpack mist blower at the rate of 1 pt/tree.



Figure 13.--Scotch pine sprayed with Bordeaux mixture for control of brown spot. Compare with the neighboring untreated tree in figure 14.



Figure 14.--Unsprayed Scotch pine with severe symptoms of brown spot needle blight.

Table 7.--Brown spot fungicide test, Trempealeau, Wis., 1971

Fungicide formulation	Rate/ 100 gal (oz)	Spray applications ¹	Foliage disease rating ²	
			Spring 1971	Fall 1971
			before spraying	after spraying
Du-ter	0	0	2.9	3.0
47.5 WP	12	1	3.0	2.7
	12	2	2.9	2.1
Bordeaux	0	0	3.0	2.8
8-8-100	(⁵)	1	3.0	1.9
	(⁵)	2	2.9	2.1
Fundilan	0	0	3.0	3.0
75 WP	96	1	2.9	1.0
	96	2	2.9	0.8
Ziram	0	0	3.0	3.0
76 WP	96	1	2.8	2.7
	96	2	3.0	3.0

¹The 1 spray was applied on June 23, 1971, the 2 sprays were applied on June 23 and August 10, 1971.

²Each rating is based on the average disease score on 30 trees.

³Unsprayed.

⁴Damage from brown spot was rated on a visual scale of 0 to 3. Trees rated 0 or 1 would be classified as merchantable Christmas trees.

⁵Bordeaux mixture was 8 lb copper sulfate and 8 lb lime/100 gal water.

results showed Bravo to be superior to Bordeaux mixture (table 8) but neither treatment was completely satisfactory. There was evidence that the trees in the center of the sprayed areas did not receive adequate coverage. There were 33 rows of trees between road systems, and this is considered to be too great a distance for complete foliage coverage.

The plantation near Poy Sippi was sprayed on June 15, 1972. Three treatments were tested: (1) Bravo W75 at 96 oz/100 gal water (plot size 2.25 acres); (2) Bravo W75 at 48 oz/100 gal water (plot size 2.25 acres); and (3) unsprayed area (2.35 acres). The road system was approximately every 20 rows. On October 11, 1972, a random sample of 100 to 200 trees from each treatment was rated

Table 8.--Brown spot pilot fungicide test using air-blast mist blower, Black River Falls, Wis., sprayed on June 14, 1972

Fungicide formulation	Rate/ 100 gal	Sample size	Spray applications	Foliage disease rating ¹ fall 1972
	Ounces	Number	Number	
Bordeaux 8-8-100	(²)	100	1	2.0
Bravo 75 WP	96	100	1	1.7
No spray	--	100	0	2.5

¹Damage from brown spot was rated on a visual scale of 0 to 3. Trees rated 0 or 1 would be classified as merchantable Christmas trees.

²Bordeaux mixture was 8 lb copper sulfate and 8 lb lime/100 gal water.

for brown spot symptoms. At Poy Sippi Bravo gave excellent control (table 9). The better control at Poy Sippi as compared to the Black River Falls plots can be attributed to more uniform fungicide coverage of the foliage. The plantation access roads at Poy Sippi were closer together and the mist blower was more powerful than the equipment used at Black River Falls.

Fungicide Control Summary

Based on 3 yrs of fungicide trials, we conclude that all of the fungicides tested will give adequate control in light to moderately infected plantations if applied when

the newly emerging needles are approximately half their total length. In heavily infected plantations where the inoculum potential is high, a second spray may be needed 3 to 4 weeks later. In these heavily infected plantations only the more effective fungicides will give adequate control. In order of effectiveness, these are: Fundilan, Bravo, and Bordeaux mixture. At present, Fundilan is not available in the United States and is not registered for use on the brown spot disease. It therefore cannot be recommended at this time. Bravo and Bordeaux mixture are registered for brown spot needle disease control and, when used at the proper time with good foliage coverage, will give excellent control of the brown spot disease.

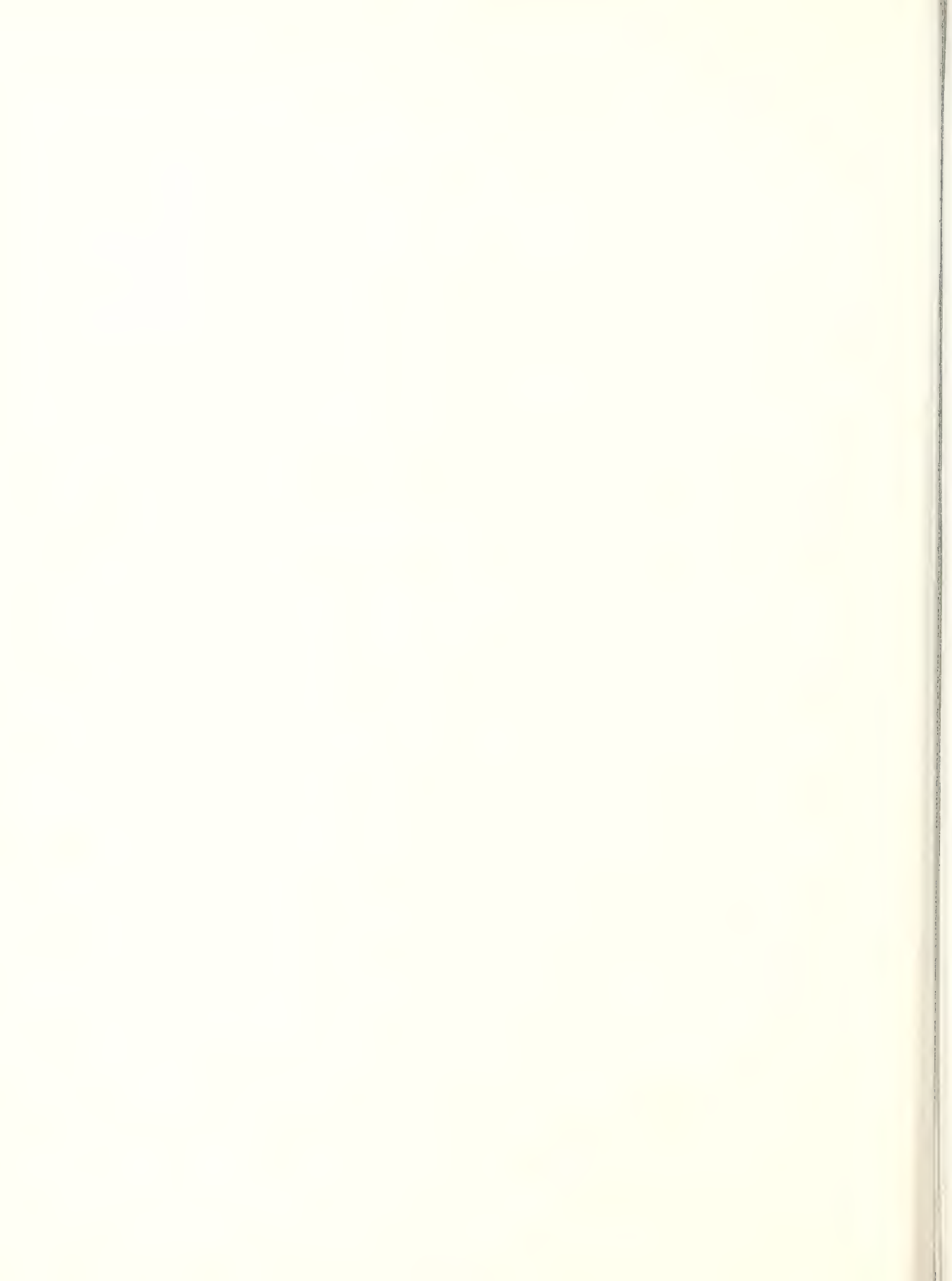
Table 9.--Brown spot pilot fungicide test using air-blast mist blower, Poy Sippi, Wis., June 15, 1972

Fungicide formulation	Rate/100 gal	Sample size	Spray applications	Foliage disease rating ¹ fall 1972
	Ounces	Number	Number	
Bravo 75 WP	96	200	1	0.4
Bravo 75 WP	48	200	1	0.7
No spray	--	100	0	2.4

¹Damage from brown spot was rated on a visual scale of 0 to 3. Trees rated 0 or 1 would be classified as merchantable Christmas trees.

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THIS IS ANOTHER OF OUR "NEW LOOK" RESEARCH PAPERS, designed (hopefully) to serve the special needs of each of our two major clients: the practitioner and the scientist.

Realizing that the needs and interests of our two major "clients"--the scientists and the practitioner--are different, we have been concerned whether our publications have been in a form and style equally useful to both. So we have decided to try a new format for some of our Research Papers, one that might serve this dual purpose better. You are about to sample the first fruit of this effort.

The Paper is divided into two separate parts: Application and Documentation. The Application section is specifically intended for the man on the ground or in the mill who has a particular job to do or problem to solve. This section describes briefly the situation and the problem, and then goes immediately to the solution, emphasizing the how-to-do-it aspect. It is a complete story in itself; the busy manager need read no further.

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Our purpose is to separate the practical aspects of our research results from the strictly academic ones yet still make both available to all readers. If the practitioner wants to find out how we arrived at our recommendations, the details are in the Documentation section for him to examine. If the scientist has a practical bent, he can turn to the Application section and see the results in action.

It is for you to decide whether we have created a well-matched team or a two-headed monster. We would like to have your opinion.



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CONTROL OF LOPHODERMIIUM NEEDLECAST DISEASE IN NURSERIES AND CHRISTMAS TREE PLANTATIONS

Thomas H. Nicholls
and
Darroll D. Skilling



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CONTENTS

Introduction	1
Extent of Damage	1
Susceptible Hosts	2
Symptoms and Life History	3
Early Detection Vital	3
How to Apply Fungicides	4
Cultural Preventatives	10
References	11

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CONTROL OF *LOPHODERMIIUM* NEEDLECAST DISEASE IN NURSERIES AND CHRISTMAS TREE PLANTATIONS

Thomas H. Nicholls and Darroll D. Skilling

INTRODUCTION

These recommendations are based upon studies initiated by the USDA Forest Service as a result of an outbreak of *Lophodermium* needlecast in several nurseries in the Lake States that spread to plantations throughout the United States due, in part, to shipments of diseased seedlings during the late 1960's and early 1970's. Results have been published at various stages of these studies (see References, page 11).

Nurseries adopting control recommendations developed and refined during the course of these studies were again producing healthy stock by 1969-1971 (figs. 1, 2, and 3). This publication is intended to provide a summation of these recommendations to be used by nursery and plantation managers for designing operational control programs patterned to their particular needs.

EXTENT OF DAMAGE

During 1966 and 1967, millions of red pine (*Pinus resinosa* Ait.) and Scotch pine (*P. sylvestris* L.) seedlings in several nurseries in Minnesota, Wisconsin, and Michigan were killed or severely damaged by the needlecast fungus, *Lophodermium pinastri* Schrad. ex Fr. Chev. (figs. 4 and 5).

Lophodermium has been reported in at least 30 tree nurseries in Maine, Michigan, Wisconsin, Minnesota, Washington, West Virginia, Pennsylvania, North Carolina, South Carolina, Ontario, and Nova Scotia (fig. 6). The disease has probably infected nurseries in many other States. Many commercial tree nurseries ship stock throughout the entire United States. As a result, *Lophodermium* has appeared in plantations wherever climatic conditions are conducive to disease development.

In 1970, serious damage from *L. pinastri* began to appear in Scotch pine Christmas tree plantations in the Lake States Region (fig. 7). By 1971 *Lophodermium* needlecast was causing catastrophic damage in plantations from the New England States to the West Coast (Skilling and Nicholls 1971).

The disease has damaged plantations in such diverse locations as British Columbia, Connecticut, Indiana, Michigan, Wisconsin, Massachusetts, Washington, North Carolina, South Carolina, Ohio, Pennsylvania, Vermont, New York, Kentucky, Oregon, Minnesota, and West Virginia (fig. 6). Several million trees were made unsalable by this disease. Therefore, Scotch pine plantations throughout the United States and Canada should be closely watched for *Lophodermium* infection. If detected, control measures for use in

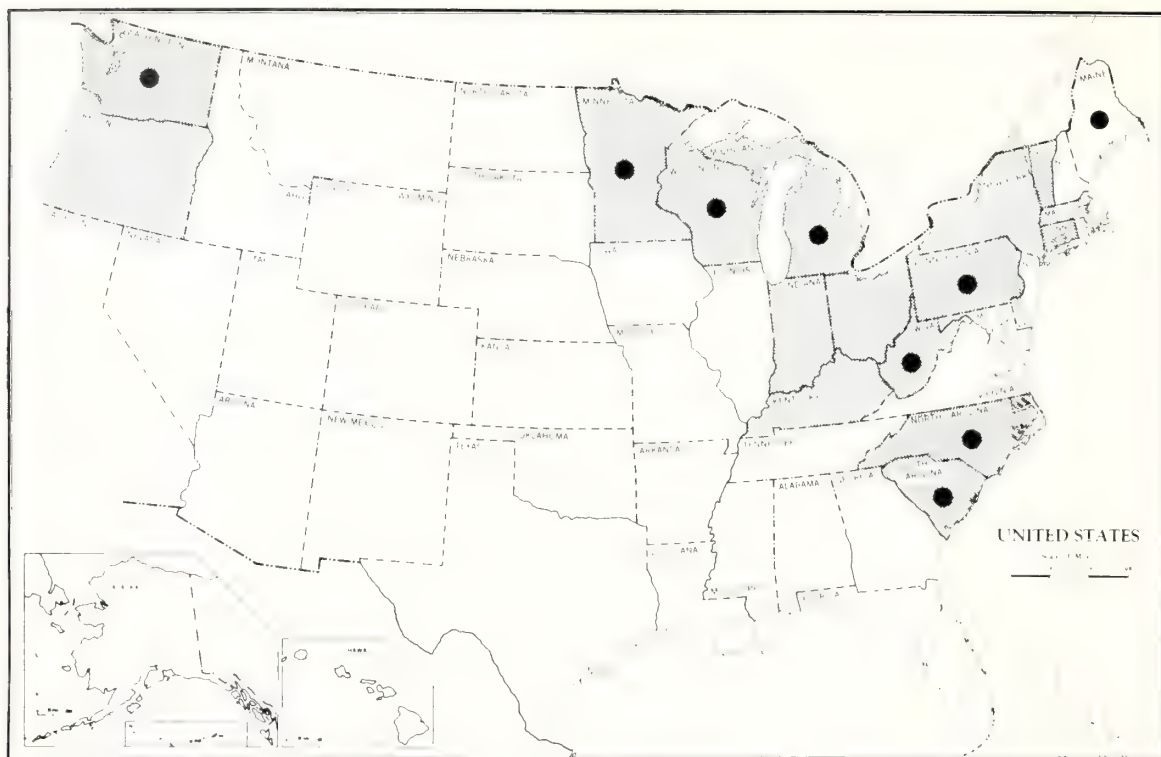


Figure 6.--Shaded States denote distribution of *L. pinastri* in Scotch pine Christmas tree plantations. States with black dots have had outbreaks of *Lophodermium* in nurseries growing red pine, Scotch pine, or both.

plantations should be started as soon as possible (fig. 8).

Before these attacks, *L. pinastri* had not been considered an important pathogen of either red or Scotch pine in the United States even though it long has been considered a serious problem in Scotch pine nurseries and plantations in Europe. There had been only one report attributing damage by it in this country: to red pine in a Massachusetts nursery; this report was published by Spaulding in 1935. The increased use of Scotch pine in the United States in both nurseries and plantations for Christmas trees may have contributed to the rather sudden buildup of the pathogenic strain in this country.

Millar and Watson (1971) recently reported on two *L. pinastri* strains found on

Scotch pine in Scotland. Both might be present in Europe and the United States. One strain seems to be entirely saprophytic, attacking only older needles that are in poor vigor. The other strain, however, is pathogenic and can attack healthy needles of all ages. It is this strain that is currently causing the problem.

SUSCEPTIBLE HOSTS

Red and Scotch pines are most susceptible to *L. pinastri*. The short-needled Scotch pine varieties are highly susceptible to damage by the fungus. Long-needled Scotch pine varieties are more resistant, but this could change if certain genetic changes occur in either the host or fungus that might increase the susceptibility of a variety.

SYMPTOMS AND LIFE HISTORY

Brown spots, often with yellow margins, are produced on needles in the spring as a result of the previous year's infection (fig. 9). These infected needles begin yellowing and turning brown in late April, May, and June. The damage is more severe on the lower parts of trees, but it is not unusual for all the foliage to be infected (fig. 10). The disease can be distinguished from winter burn because only the foliage above the snowline turns brown on winter-burned trees (fig. 11). On some trees both winter burn and *Lophodermium* may be found.

Lophodermium fruiting bodies develop on the brown needles that fall off trees in June and July, many of which lodge in the trees. They also develop on dead needles still attached to tree branches. These fruiting bodies mature by late August and look like tiny, black, football-shaped structures having a longitudinal slit down the center. During rainy weather in August, September, and October, these fruiting bodies absorb moisture, their slits open, and their fungus spores are forcibly discharged into the air (fig. 12). When these windborne spores land on red or Scotch pine needles, the spores germinate and infect the needles if environmental conditions are favorable. Control measures must be taken before this time if foliage is to be protected.

By late fall, most of the dead needles are cast, which leaves only the current-year needles on the trees (fig. 13). Trees in this condition are unsalable as Christmas trees. In nurseries, there is often high mortality in young seedlings (fig. 5). In nurseries as well as plantations, most older trees survive by the development of new needles the following spring. These new needles become infected in late summer and fall and the disease cycle is repeated.

EARLY DETECTION VITAL

Nurseries and plantations should be closely watched for outbreaks of *Lophodermium*, particularly in the spring when symptoms are most evident (fig. 14). Train workers to be alert for infected trees on

LOPHODERMIIUM SPORE RELEASE DATA FOR MINNESOTA, WISCONSIN,
MICHIGAN, INDIANA 1969 - 1972

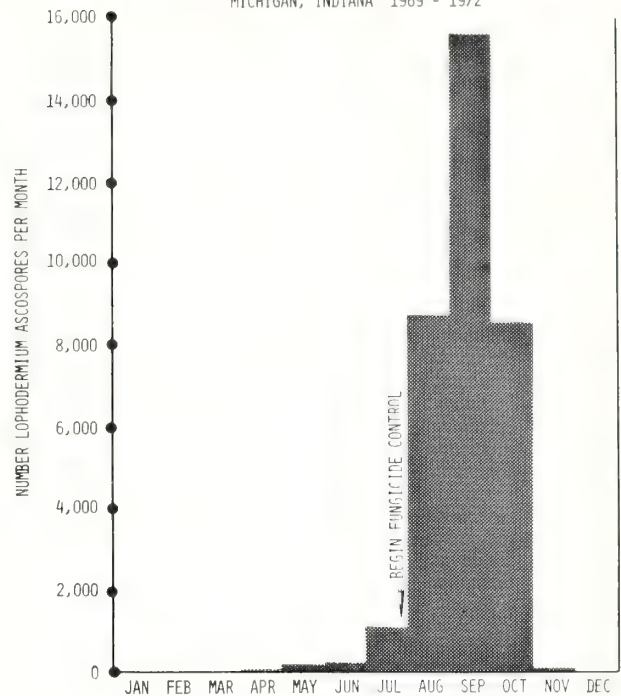


Figure 12.--Combined *Lophodermium* spore release data obtained in nurseries and Christmas tree plantations in Minnesota, Wisconsin, Michigan, and Indiana, 1969-1972. For effective control, fungicides must be applied to foliage just before and during the major spore dispersal period which begins in August and continues into October. September is the key month for spore release and infection in all four States in both nurseries and plantations.

which over 20 percent of their total foliage is brown in May or June. When such trees are detected, contact the local Extension Forester or Forest Pest Management office to arrange for positive identification by a plant pathologist. This service is usually available free from the following agencies: Plant Disease Clinics, Departments of Plant Pathology, State Universities; Plant Pest Divisions, State Departments of Natural Resources or Agriculture; or Forest Pest Management, State and Private Forestry, USDA Forest Service.

Early detection will prevent serious economic losses for growers because control

can be achieved faster in lightly infected nurseries and plantations. It is essential that the protective fungicide be applied before the fungus spores discharged by the fruiting bodies land on healthy needles during rainy periods in August, September, and October (fig. 12).

In plantations, it usually takes 2 to 3 yrs for *Lophodermium* to reach epidemic status because the disease might subside during dry years and then increase in severity as soon as normal moisture conditions return. In nurseries where irrigation is used and where seedlings are grown in densely packed, moist beds, the disease can reach epidemic conditions each year.

HOW TO APPLY FUNGICIDES

When Not To Spray

Fungicides should not be applied during rain because it will wash off before it has an opportunity to dry on the needles. Once dried, fungicides resist rainfall; chlorothalonil more so than maneb. Moreover, there is some evidence that rain redistributes chlorothalonil residues over the foliage after it has dried on needles. Do not spray when it is windy because this prevents even foliage coverage. Do not spray plantations that do not show signs of *Lophodermium* infection unless they are in danger of infection from adjacent infected plantations.

When To Spray

The exact timing of control procedures may vary somewhat with geographical location. The following recommended spray schedules apply generally to the Lake States and Northeastern States. For other areas, determine the major *Lophodermium* spore release and infection periods and apply one of the recommended fungicides before spore release and follow with other sprays at 2- to 3-week intervals during the major spore-release periods.

Nursery.--For maximum control, four sprays should be applied just before and during the period when *Lophodermium* fruiting bodies are mature and spores are released (fig. 12). Sprays should be applied about

August 1, and 15, and September 1, and 15. In areas where infection is high, an October 1 spray may also be required if there is prolonged rainy weather.

Plantations.--Infected plantations should be sprayed three times: about July 25 (when new foliage is fully elongated), about August 15, and about September 10. An additional spray in late September or early October may be required if there is unusually wet weather during this period.

Nursery stock has high value per acre; therefore, it is economically feasible to invest in the more intensive spraying schedule recommended for nurseries, which would be impractical for plantations. The objective for using fungicides in nurseries is complete control to ensure that more plantations will not be infected by the introduction of diseased seedlings. The objective for using fungicides in plantations is to produce healthy trees having dense foliage that will be salable on Christmas tree lots, which the recommended spray schedule will do effectively.

What To Use

Two fungicides are currently registered for control of *Lophodermium* needlecast: chlorothalonil (tetrachloroisophthalonitrile) (Bravo W-75, Daconil 2787, Bravo 6F) and maneb (Manganese ethylene bisdithiocarbamate) (Manzate 200, Manzate D, Dithane M-22, Dithane M-45).¹ Both are easy to handle, non-corrosive to spray machinery, relatively safe, and have proved effective in controlling *Lophodermium* in tree nurseries and Christmas tree plantations. Both are compatible with wettable powder formulations of most commonly used fungicides, insecticides, and miticides. Follow label for emulsifiable formulations.

Benomyl (methyl 1-(butylcarbamoyl)-2-benzimidazolecarbamate) (Benlate) provides excellent *Lophodermium* control, but it has not, as yet, been registered for this use (Nicholls 1973).

¹Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.



Figure 1.--Maneb-protected 2-0 red pine in the foreground; unprotected beds in the background. Heavy mortality caused by *L. pinastri* occurred in the unprotected trees. (Picture taken in June 1969.)



Figure 2.--Maneb-treated 3-0 red pine are healthy. The bed to the left, with the brown trees, was not sprayed with maneb and the trees were heavily infected. Note that some infected trees are recovering by development of the terminal bud. (Picture taken in June 1969.)



Figure 3.--Infrared picture of 2-0 red pine. Beds that are bright red had been sprayed with maneb and are healthy as indicated by the red color. The bed that is not bright red was not sprayed and the trees were killed or heavily damaged by *L. pinastri* as indicated by the tannish-brown color of the foliage. (Picture taken in May 1969.)



Figure 4.--Three-yr-old red pine infected with *L. pinastri* in a Wisconsin nursery. Whole tree beds turned brown in several nurseries during the spring of 1966.



Figure 5.--Spanish Scotch pine seedlings in a Michigan nursery killed by *L. pinastri* during June 1968.



Figure 8.--The Scotch pine on the left was an unsprayed tree and the one on the right was sprayed three times in late summer and fall with a fungicide and was protected from infection.



Figure 7.--A Spanish Scotch pine Christmas tree plantation heavily infected with *Lophodermium* needlecast. (Picture taken in May 1973.)

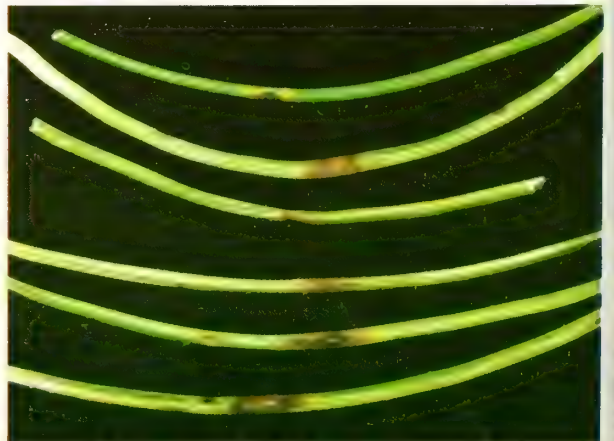


Figure 9.--Needle spots on red pine caused by *L. pinastri*. The fungus eventually destroys the vascular system in needles after which entire needles turn brown.



Figure 10.--*L. pinastri*-infected Scotch pine Christmas tree. (Picture taken during the spring of 1973.)

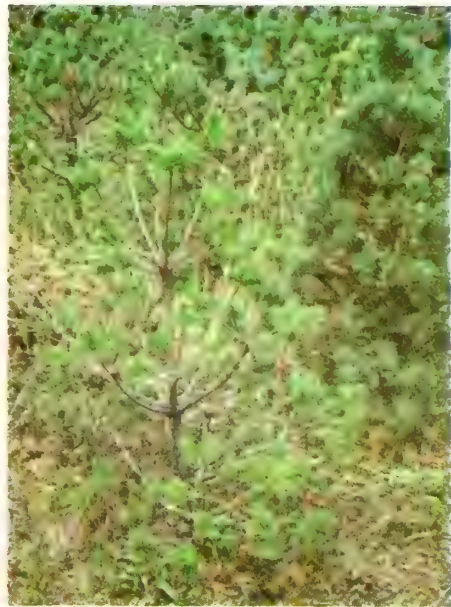


Figure 13.--By late summer and fall only current-year needles remain on heavily infected trees. Such trees are of poor quality and not salable as Christmas trees.



Figure 11.--A winter-burned Scotch pine Christmas tree during the spring of 1972. Note how the branches that were below the snowline, and protected from the wind and sun, remained green. Compare this to figure 10 where *Lophodermium* has infected all of the foliage including the branches next to the ground.



Figure 14.--Here a nursery manager is closely checking for the presence of *L. pinastri* on red pine nursery stock under the guidance of a plant pathologist. Early detection and control of *Lophodermium* will prevent serious economic losses.



Figure 15.--A highboy hydraulic sprayer used by some Christmas tree growers to apply fungicides to tree foliage.



Figure 17.--In large plantations aerial spraying may be the most economical method of applying a control fungicide.



Figure 16.--A roto-blast mist blower is generally the most economical method of applying a fungicide in Christmas tree plantations for *Lophodermium* control. In some situations, aircraft application may be somewhat more economical (see fig. 17).



Figure 18.--Hydraulic sprayers are used by nurseries to apply maneb or chlorothalonil to red and Scotch pine beds for *Lophodermium* control.

Some States have restrictions on the use of certain pesticides. Check your State and local regulations. You should consult your county agricultural agent or State extension specialist to be certain the intended use has been or is still registered because registrations of pesticides are under constant review by the Federal Environmental Protection Agency.

Bordeaux mixture, which has been used extensively for control of brown spot (*Scirrhia acicola*) in Christmas tree plantations, is not effective against *Lophodermium* and is not recommended.

Application Equipment

Most Christmas tree growers use hydraulic sprayers, mist blowers, or aircraft for fungicide spraying (figs. 15, 16, and 17) while most nurserymen use hydraulic sprayers (fig. 18). To be effective, sprayers must be operated at sufficient pressure to completely moisten all tree foliage. A tank agitator is recommended to ensure uniform dispersion of the fungicide; this prevents the fungicide from settling to the bottom of the tank. The agitator should be operated while (a) the tank is filling with water, (b) the fungicide is being added, and (c) the fungicide is being applied.

Chemical Concentrations And Methods of Application

As shown in table 1, chlorothalonil or maneb should be applied at the rate of 2-1/2 lb commercial/acre in 100 gal of water using a hydraulic sprayer. If flowable chlorothalonil is used, 2-1/2 pt in 100 gal of water would be required. A surfactant (such as DuPont spreader-sticker) is needed for maneb; the amount needed is 4 oz/100 gal of water. A spreader-sticker is not needed for chlorothalonil.

Nurseries.--Spray nozzles on hydraulic sprayers should be held within 15 to 20 in. of the trees. Nozzles should be spaced about 20 in. apart on the spray boom. Depending upon the age class of the trees being sprayed, the boom can be lowered or raised to provide full coverage of the foliage. About 2-1/2 lb of fungicide in 100 gal of water will cover about an acre if a flat

Table 1.--Amount of commercial maneb or chlorothalonil (wetable powder) needed to control *Lophodermium* according to different kinds of application equipment

Equipment	Fungicide ¹	Water	Approximate area of coverage
	Lbs	Gal	Acres
Hydraulic sprayer	2-1/2	100	1
Roto-mist blower	6	100	2-1/2
Low-volume mist blower	12-1/2	100	5
Fixed-wing aircraft	2-1/2	5-10	1

¹If flowable chlorothalonil is used, 1 pt is equal to 1 lb of wettable powder.

spray Tee Jet nozzle No. 8008 (52 GPA) is used on a hydraulic sprayer moving at 3 mi/h.

Christmas tree plantations.--Mist blowers moving at 2 mi/h will cover more area per hour (8 acres) than hydraulic sprayers in Christmas tree plantations. Thus, the hydraulic sprayers are more expensive to operate, but they do provide good coverage. Hydraulic sprayers use about 100 gal of water/acre; roto-mist blowers only about 40 gal/acre. Consequently, the fungicide concentration used for hydraulic sprayers (2-1/2 lb/100 gal of water) is much lower than that used for the roto-mist blowers (6 lb/100 gal of water). These mist blowers develop wind-speeds up to 95 mi/h and up to 15 rows of trees can be sprayed where trees can be sprayed from both sides of a road (fig. 16). The new low-volume mist blowers use only about 20 gal/acre; thus, the fungicide concentration would be 12-1/2 lb/100 gal of water to obtain field coverage of 2-1/2 lb/acre.

Safety Precautions

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key--out of reach of children and animals and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

CULTURAL PREVENTATIVES

There also are a number of cultural practices that nurserymen and growers can follow that will either prevent *Lophodermium* infection or reduce its severity.

Nursery

● Windbreaks should not be of the same species as grown in adjacent nursery beds. Nurseries experiencing *Lophodermium* losses often have red or Scotch pine windbreaks adjacent to the nursery beds. Infected windbreaks may play a major role in the buildup of *L. pinastri* when spores or infected needles having fungus fruiting bodies are blown into nursery beds.

● Transplant stock should not be brought into nurseries from other areas. Several

new diseases have been introduced from one nursery to another by shipping infected stock between nurseries.

● Do not ship infected nursery stock for outplanting. This will prevent the development of an epidemic in the field caused by infected nursery stock.

● If irrigation is needed in late summer and fall, it should be done in the morning to allow the trees time to dry during the afternoon. This prevents prolonged periods of moisture that are conducive to *Lophodermium* infection.

Plantation

● Plant only healthy nursery stock. This seems obvious enough, but many times the grower is so eager to get the plantation established that he will plant unhealthy trees. If stock has turned brown when received, or if it has numerous infection spots on the foliage, the trees should be examined by a plant pathologist before they are planted. Infected trees should be returned to the nursery because it is far cheaper to keep disease out of a plantation than to control it once it is established. Although State nursery inspection is improving, there have been many cases in recent years where stock was shipped from nurseries with foliage diseases present.

● Avoid planting Scotch pine seedlings next to Scotch pine windbreaks. These windbreaks frequently serve as a reservoir for the *Lophodermium* fungus as well as other insect and disease problems. These windbreaks should be cut and burned the year before a new stand is planted. Stumps should either be removed or treated with a registered insecticide.

● Avoid shipping diseased Christmas trees. Christmas trees are shipped to many different parts of the country. This is a good way for a disease to be transported and to become established in new areas.

● When harvesting trees, especially in infected plantations, avoid leaving live branches on stumps. These lower branches are especially susceptible to foliage

disease problems and their needles serve to perpetuate the *Lophodermium* fungus.

● Do not plant just one species or variety. To avoid catastrophic losses, a grower should not plant his land with only one species or variety of conifer. If a disease damages one species, there is a good chance that it will not damage other species being grown.

● Plant resistant Scotch pine varieties or other conifer species. Avoid planting highly susceptible short-needled Scotch pine varieties such as the "Spanish" and "French-green" varieties. Long-needled Scotch pine varieties such as the "Scottish Highland" or "Austrian Hills" are more resistant to attack. Other conifer species such as white pine, white and blue spruce, and balsam fir

could be planted for Christmas trees to avoid *Lophodermium* damage. However, these species sometimes are attacked by other species of fungi.

Resistance to *Lophodermium* may eventually be increased by selecting resistant provenances or individual trees and by breeding resistant strains. Research of this type will be necessary if Scotch pine continues as the number one Christmas tree produced and bought in the United States. Red pine appears to acquire resistance to the fungus as trees get older, unlike Scotch pine, which appears to be susceptible at all ages. This may be the reason we have not observed a *Lophodermium* outbreak in red pine Christmas tree plantations even though heavy damage has occurred to red pine seedlings in some tree nurseries.

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Sing along with Woody and help stop pollution.



prescribed **BURNING**
in the
North Central
States

LINDA R. DONOGHUE - VON J. JOHNSON

CONTENTS

History of prescribed burning in the Lake States . . .	1
The survey	2
Number of fires and burned acreage	2
Purpose of burn	2
Fuels	4
Weather	5
Other aspects	7
Literature Cited	8

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PREScribed BURNING IN THE NORTH CENTRAL STATES

Linda R. Donoghue and Von J. Johnson

We know that prescribed fire is used in the Lake States region, but we do not know to what extent. In an effort to find out, we began an annual survey in 1968 in Michigan, Minnesota, and Wisconsin and included Illinois and Ohio in 1972. This report summarizes 5 years' results.

HISTORY OF PRESCRIBED BURNING IN THE LAKE STATES

Prescribed fire has not been used extensively in the Lake States. This may be due in part to the region's fire history. The great fires of the latter 19th and early 20th centuries prompted intensive and highly effective prevention and suppression campaigns that discouraged prescribed burning. Although prescribed fire was proposed during this period, it was rejected in the belief that public misinterpretation and misunderstanding would cause more harm than good (Chapman 1947). A controversy, lasting nearly 20 years, developed over the relative merits of controlled fire versus total exclusion, following an early report by Chapman (1926).

The increased use of prescribed burning in the southern United States lent credibility to the idea of fire as a management tool. By 1939 prescribed fire in longleaf pine was officially recognized at the national level (Chapman 1947). As a result of southern success, managers began

burning in other parts of the country. Research trials for silvicultural purposes and hazard reduction were conducted by the Lake States Forest Experiment Station beginning in the 1930's (Buckman 1964). In 1935 prescribed burning was advocated by game managers as a means of controlling forest encroachment into wildlife habitat in the Lake States (Smith 1947). In the early 40's Maissurow (1941) stressed fire's role in the perpetuation of yellow birch, hemlock, pines, and the intolerant hardwoods in northern Wisconsin. Within the decade burning for wildlife habitat improvement increased rapidly in Wisconsin and Michigan. During the 1950's, however, much of the burning in the other Lake States remained experimental, even though a few agencies accepted controlled burning as a commonplace management practice.

Operational use of prescribed fire increased in the 1960's. This increase was largely due to preceding research efforts that provided favorable information to land managers. Large amounts of technological and ecological information on fire effects were produced during the 60's by researchers such as Beaufait (1962), Chrosiewicz (1967), and Ahlgren (1970). Presently, the greatest usage of prescribed fire in the Lake States is for wildlife habitat management (Donoghue 1973, 1974). It is also used for such things as hazard reduction, planting site and seedbed preparation, insect and disease control, and hardwood regeneration.

THE SURVEY

A questionnaire was sent to all known users of prescribed fire in Minnesota, Wisconsin, and Michigan annually over a 5-year period from 1968 through 1972. In 1972 Ohio and Illinois were also included. Several agencies participated in the survey. They include the Minnesota, Wisconsin, Michigan, and Ohio Departments of Natural Resources; University of Minnesota; Forest Service; U.S. Bureau of Sport Fisheries and Wildlife; other U.S. Department of Interior agencies; and a few private landowners.

Unfortunately, there is no standard procedure for routinely reporting prescribed fires. The data used in this analysis are limited to the responses received from co-operating agencies and do not necessarily include all prescribed burning within the surveyed area. The analysis in some cases necessitated interpretation of the primary ages of burning slash, burning techniques, and purpose-of-burn.

NUMBER OF FIRES AND BURNED ACREAGE

The number of prescribed fires reported by participating agencies increased from 72 in 1968 to 115 in 1972. This trend may indicate either increased use of prescribed fire or more complete reporting response. The Minnesota Department of Natural Resources submitted almost half of the 444 reports received; the Wisconsin Department of Natural Resources submitted nearly one-fourth.

More burned acreage was reported during 1968 and 1970 than in other survey years. Although the number of fires increased through the reporting period, acreage burned did not always follow this trend. In some years more prescribed fires were conducted, but less acreage was burned per fire.

During the 5-year period 76,743 acres were prescribed burned (table 1). Wisconsin reported 22,570 acres or 29 percent of the total and the Forest Service 21,814 acres. Although less area was burned in Minnesota (14,187 acres), that State used fire for more purposes than other reporting agencies.

Prescribed burning reaches a peak in late April, decreases sharply to a low in early June, and gradually increases again to a second peak in late August (fig. 1).

The increase of prescribed fires in late October is largely a result of acceptable burning conditions during 1972. Within the 5-year period burning began as early as February and continued into December. Monthly activity ranged from a low of 1 fire in February to 108 fires in August.

PURPOSE OF BURN

Many prescribed burns are designed to accomplish more than one objective. For instance, a prescribed fire always reduces the fuel accumulation, and with some modification, hazard-reduction burns can improve wildlife habitat. In addition, almost any prescribed burn improves access and visibility (Mobley *et al.* 1973).

Although more than one purpose was reported on 28 percent of the responses, only the primary purpose is shown in the following tabulation:

<i>Primary Purpose</i>	<i>Percent of Total Burns</i>
Wildlife habitat management	40
Site preparation	24
Seedbed preparation	23
Hazard reduction	7
Prairie grass regeneration	2
Experimental	2
Other ¹	2
	100

Ninety percent of the 22,570 acres reported by Wisconsin were prescribed burned for wildlife habitat management. The U.S. Bureau of Sport Fisheries and Wildlife (BSFW), other Department of the Interior agencies, and the State of Minnesota also burned large acreages for this purpose. Approximately 23 percent of the total reported burned by the Forest Service was for hazard reduction. Most burning for site and seedbed preparation was done by Minnesota, the Forest Service, and Wisconsin.

Burning results depend greatly upon weather and condition of vegetation. If we delineate the prescribed fire season on the basis of the phenological stage of the lower vegetation, then in the Midwest the spring burning season ends about the latter part of May, and summer season includes

¹Includes prescribed fire for natural area maintenance and disease control.

June to mid-September. Fall season is from mid-September until winter snow. These are the times when low vegetation changes from transitional to the green stage in the spring and returns from green to transitional in the fall (Haines, Johnson, and Main 1974).

Prescribed burning for various purposes follows different seasonal patterns, (table 2). Most burning took place during the spring. Wildlife habitat management, hazard reduction, and prairie grass regeneration burns were done primarily at this time. There was less

Table 1.--A summary of reported prescribed burns in the North Central States, 1968-1972

Agency	Purpose	Area Burned acres
USDA Forest Service	Hazard reduction	17,484
	Wildlife habitat management	510
	Site preparation	1,152
	Seedbed preparation	180
	Site and/or seedbed preparation	2,068
	Blueberry production	70
	Experimental	350
Minnesota Department of Natural Resources	Hazard reduction	256
	Wildlife habitat management	7,073
	Site preparation	2,744
	Seedbed preparation	3,082
	Blueberry production	121
	Natural area maintenance	235
	Disease control	387
	Prairie grass regeneration	136
	Experimental	153
Wisconsin Department of Natural Resources	Hazard reduction	386
	Wildlife habitat management	20,334
	Site preparation	1,377
	Seedbed preparation	122
	Prairie grass regeneration	351
Michigan Department of Natural Resources	Wildlife habitat management	1,725
	Site preparation	110
U.S. Bureau of Sport Fisheries & Wildlife	Hazard reduction	31
	Wildlife habitat management	9,662
	Experimental	303
Private landowners	Wildlife habitat management	120
	Site preparation	84
Other Department of the Interior agencies	Hazard reduction	372
	Wildlife habitat management	4,659
	Seedbed preparation	40
	Prairie grass regeneration	85
	Experimental	27
Ohio Department of Natural Resources	Wildlife habitat management	54
University of Minnesota	Experimental	570
Minnesota Department of Natural Resources in cooperation with Univ. of Minn.	Experimental	330
TOTAL		76,743

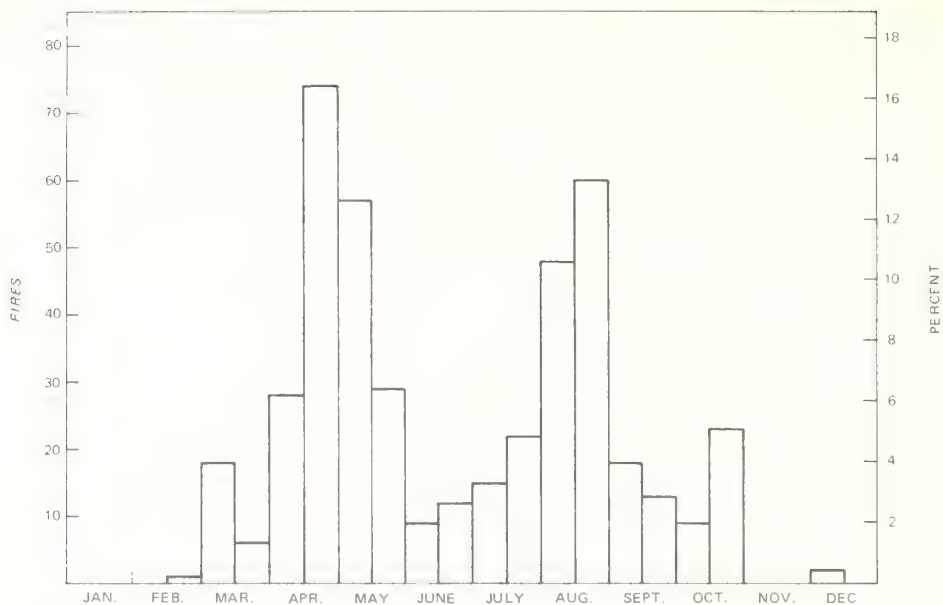


Figure 1.--Total number and percent of prescribed fires by half-months, 1968-1972.

Table 2.--Primary purpose of prescribed fire by season (In percent)

Purpose	Seasons		
	Spring	Summer	Fall
	(Last snow to May 31)	(June 1 to Sept. 15)	(Sept. 16 to first snow)
Wildlife habitat	26	10	4
Site preparation	9	12	4
Seedbed preparation	4	16	2
Hazard reduction	5	1	(²)
Prairie regeneration	2	0	(²)
Other ¹	2	2	0
TOTAL	48	41	11

¹Includes burns for experiment purposes, training, and disease control

²Less than 1 percent

activity in the summer, although most seedbed-preparation burns took place during this season. Prescribed burning for site preparation, experimental purposes, natural area maintenance, and disease control also occurred primarily during the summer months. Little fall burning was reported.

Fuel Group	Percentage of Total Burns
Conifer	57
Grass	17
Hardwood	14
Brush	6
Fuels not reported	6

FUELS

The fuels burned were divided into four main groups:

More than half the prescribed burns were ignited in coniferous fuel, primarily jack pine, black spruce, or balsam fir. Most

slash was burned when 1 or 2 years old, even though slash age ranged from current to 10 years old.

The type of fuel burned varied with the time of year (table 3). During the spring most prescribed fires were in hardwood, brush, and grass fuels. Burning in coniferous fuels took place largely during

the summer months. In most cases the fuel type burned and the purpose of the burn were directly related. For example, most burning for wildlife habitat improvement took place in hardwood, brush, and grass fuels during the spring. Prescribed fires for site and seedbed preparation were conducted primarily in coniferous fuels during the summer.

Table 3.--Primary fuels burned by season

(In percent)

Fuels	Season		
	Spring (Last snow to May 31)	Summer (June 1 to Sept. 15)	Fall (Sept. 16 to first snow)
Conifer	21	31	7
Hardwood	11	3	1
Brush	5	2	1
Grass	10	6	2
TOTAL	47	42	11

WEATHER

Relative humidity, temperature, insolation, and rainfall are important elements to consider in controlled burning. These factors influence fuel moisture and combined with air mass stability and wind speed, largely determine rate-of-spread and fire intensity.

After a rainfall heavy fuels and duff require several days of drying weather to reduce their moisture content to the point where they will be consumed. Fine fuels dry more quickly and may require only 1 or 2 drying days for a successful burn (Sando and Dobbs 1970). Forty percent of the burns were conducted 3 to 5 days after the last rain, regardless of fuel type (fig. 2). A few fires were not started in hardwood and brush fuels until 20-25 days after the last reported rain. Maximum air temperatures reported during prescribed burning ranged from 28° F to 91° F. Approximately three-fourths of the reported prescribed fires were conducted on days with maximum air temperatures ranging from 60° F to 89° F.

Fine fuels respond quickly to changes in humidity, whereas larger pieces of slash

may require days or weeks to adjust to variations in humidity (Beaufait 1966). Reported relative humidity during burning ranged from a low of 15 percent to a high of 85 percent (fig. 3). Humidities reported most often during burning fell between 41 and 50 percent. Seventy-five percent of the prescribed fires took place on days with humidities between 31 and 60 percent.

Wind is critical during a prescribed burn. Both velocity and directional changes can have significant effects on fire behavior. As one might suspect, prescribed burning decreased as windspeeds increased; less than 1 percent of the burns were made with windspeeds in excess of 26 mi/h.

Fire weather forecasts supply information needed to determine smoke management and fire behavior. Requests for special fire weather forecasts generally increased over the course of the survey period. In 1968, forecasts were requested for about a quarter of the prescribed fires. By 1971 special forecasts were used for 50 percent of the burns and remained close to this level in 1972.

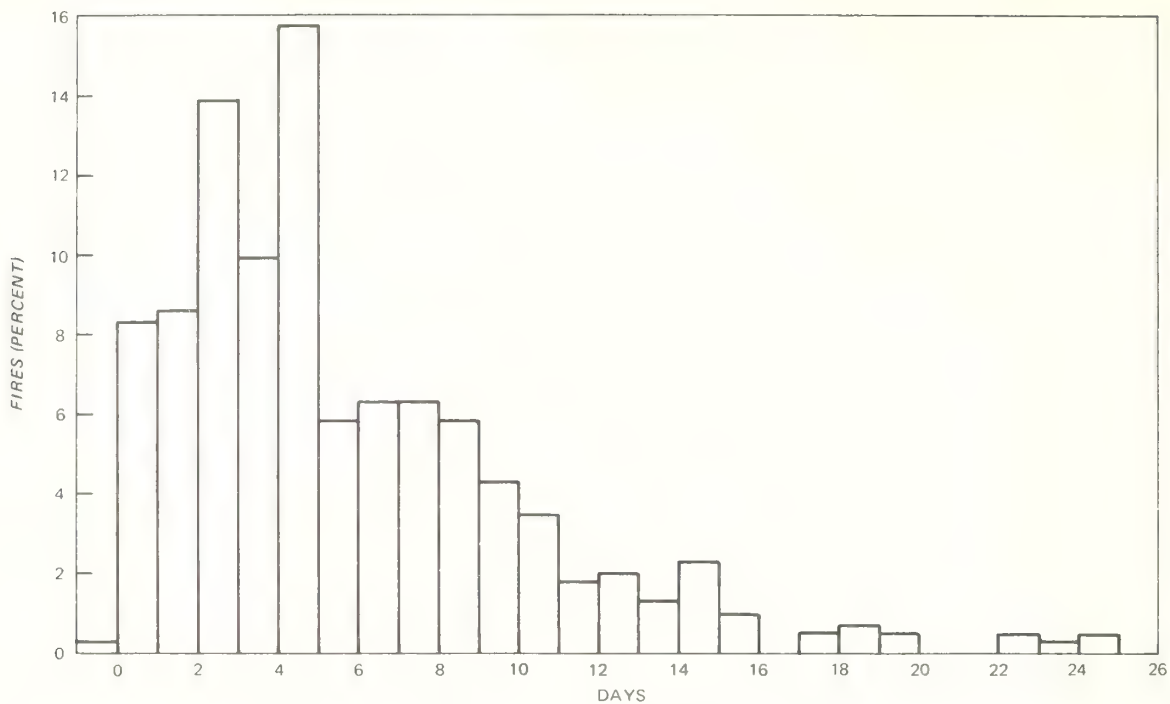


Figure 2.--Percent of burns from day of last rain.

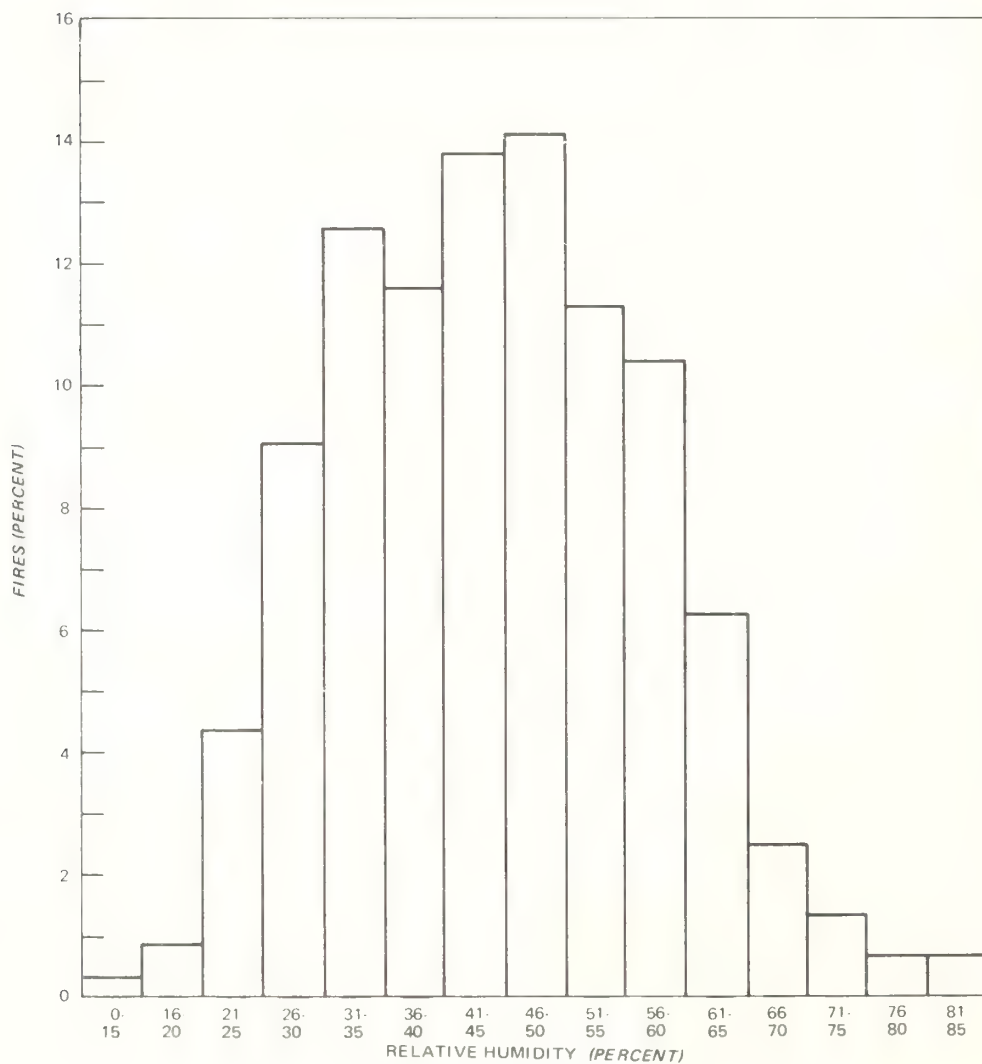


Figure 3.--Relative humidity at fire start.

OTHER ASPECTS

The time of day largely determines burning conditions. Daily variation in conditions is as important as seasonal change in scheduling fires. Three-fourths of the reported prescribed fires were started between 11:00 a.m. and 3:00 p.m., although burns began as early as 8:30 a.m. and as late as 8:30 p.m. Nearly one-third of the burns were set between noon and 1:00 p.m. Most prescribed fires were completed in 1-2 hours. About 77 percent of the reported prescribed fires were finished in times ranging from one-half hour to 4 hours.

Ignition crews should be equipped with devices that provide rapid, controlled lighting of fire along predetermined routes. The drip torch was the preferred ignition tool (81 percent) in the North Central States.

A combination of firing techniques was the decided preference on most of the fires, with the strip head-fire the single preferred technique (22 percent). Strip back-fires (12 percent), flank-fires (5 percent), and checkerboard spotting (2 percent) were also used by some managers.

Cost-per-acre varied with the purpose of burn (fig. 4). The cost for site-preparation, seedbed, and hazard-reduction burns follow the same general pattern with a few exceptions. Slightly less than half the site-preparation burns generated costs ranging from \$5 to \$10 per acre, while costs reported most often for seedbed and hazard fires ranged from \$1 to \$5 per acre. The low cost of hazard-reduction fires (\$.01 to \$.50) was a result of large acreages burned per fire.

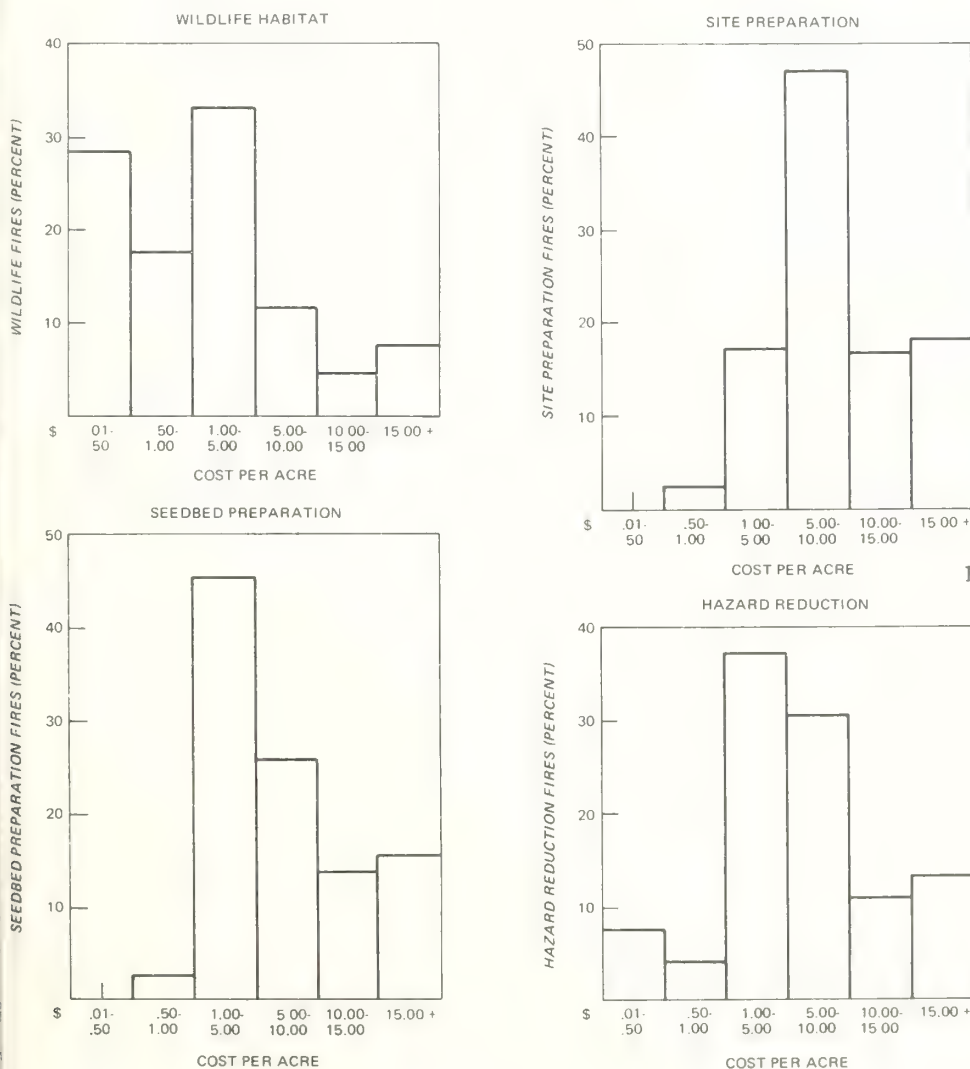


Figure 4.--Cost-per-acre by primary purpose of burns.

Expenditures reported for wildlife-habitat burns resulted in a different distribution, having lower overall costs per burn. Nearly three-fourths of the fires ranged in cost from \$.01 to \$5.00 per acre. These lower values were due to the large acreage burned per fire.

None of the fires escaped control. Seventy-four percent of the prescribed fires were reported as successfully accomplishing a primary objective. Twenty-four percent of the burns were a partial success, while the remaining 2 percent failed to accomplish the desired results. We must realize, however, that the ultimate success of a burn might not be determined for some time. Therefore, the immediate results do not always indicate the final effects of the fire.

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There is beauty in the way you think.

HELP IN MAKING FIRE MANAGEMENT DECISIONS



PETER J. ROUSSOPOULOS
and
VON J. JOHNSON



NORTH CENTRAL FOREST EXPERIMENT STATION
FOREST SERVICE
U.S. DEPARTMENT OF AGRICULTURE

CONTENTS

The Approach.	1
What the Graphs Show.	5
How to Use the Graphs	11
Conclusion.	14
Literature Cited.	16

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HELP IN MAKING FUEL MANAGEMENT DECISIONS

Peter J. Roussopoulos and Von J. Johnson

Forest management activities such as cutting or thinning of timber for harvest, constructing roads, or clearing rights-of-way, generally leave large amounts of foliage and woody debris on or near the ground. Besides being unsightly and possibly jeopardizing various forest resources, this debris becomes potential fuel for forest fires. Fires in these surface fuel accumulations are generally difficult to control and can quickly spread into surrounding stands of valuable timber. When large amounts of debris are created by forest operations, it is often desirable to treat or remove it to protect forest and human resources from damage by fire. Whether treatment is actually needed, what to do, and when to do it, however, are decisions frequently made on a subjective or arbitrary basis.

To be more realistic and effective, such decisions should be based upon answers to these four questions:

1. What level of fuel hazard is the fire control organization prepared to handle?
2. What is the post-cutting slash hazard?
3. If the slash hazard exceeds what the control organization is prepared for, what can be done to reduce it to an acceptable level?
4. How should priorities for treatment be ordered when more than one area requires treatment?

Fuel hazard is an expression of the flammability of forest fuels.

To effectively manage fuel, then, decision-makers must be able to predict fuel flammability from what is known about the fuels themselves and local weather regimes. We have devised a method for making these predictions, thereby providing approximate answers to the four questions listed above. It permits comparing man-created fuel hazards with one of several fuel hazard "standards" used for fire control planning.

THE APPROACH

Anderson (1971) suggested using the Rothermel (1972) fire model to predict potential fire behavior for evaluating planned management practices in terms of fuel hazard, before the fact. The National Fire Danger Rating System (Deeming *et al.* 1972) is based on fire behavior predictions made by this model. Moreover, Rothermel and Philpot (1973) used the model to predict the flammability of chaparral, permitting land management consequences to be analyzed in terms of future fuel hazard. In slash fuels, Rothermel's predictions are reasonably accurate (Brown 1972), and they seem suitable for rating slash fuel hazard. Our system for managing North Central and Northeastern logging slash involves using Rothermel's model to construct a series of graphs that display fuel hazard for seven species of slash (figs. 1-7). They relate hazard to slash loading, depth, condition of foliage and local "average bad" weather conditions.

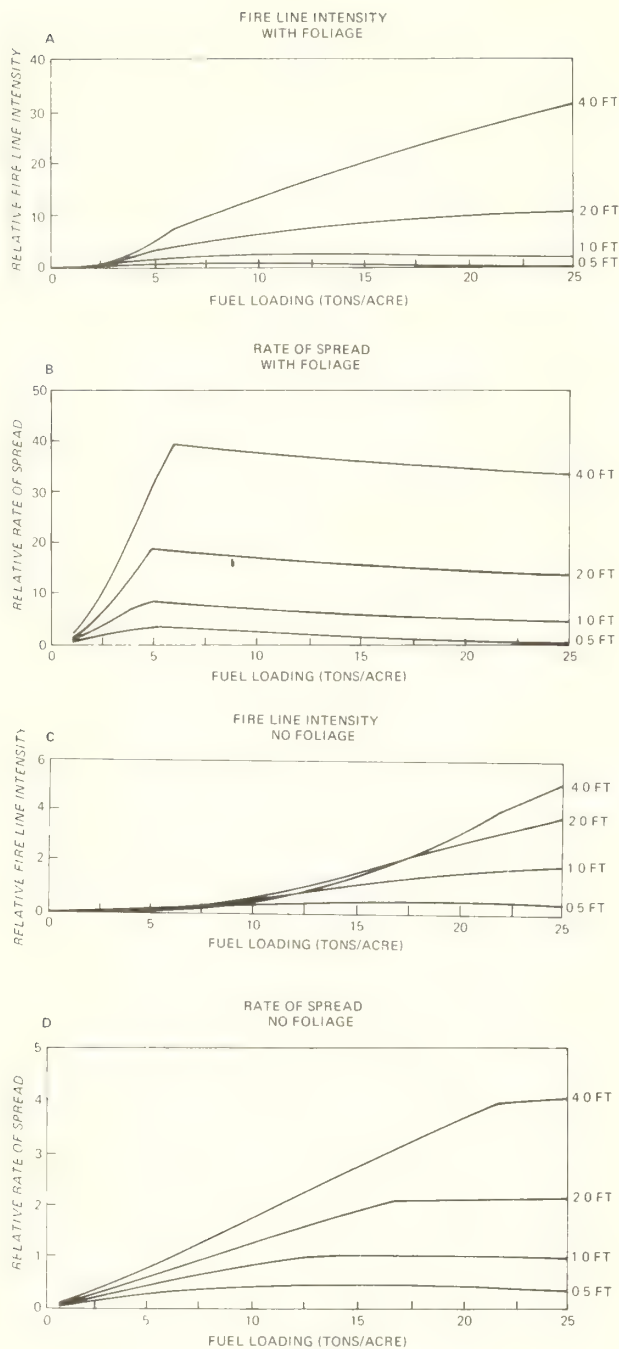


Figure 1.--Relative fire line intensities and rates of spread for jack pine slash; wind = 14 mi/h; moisture content = 6 percent.

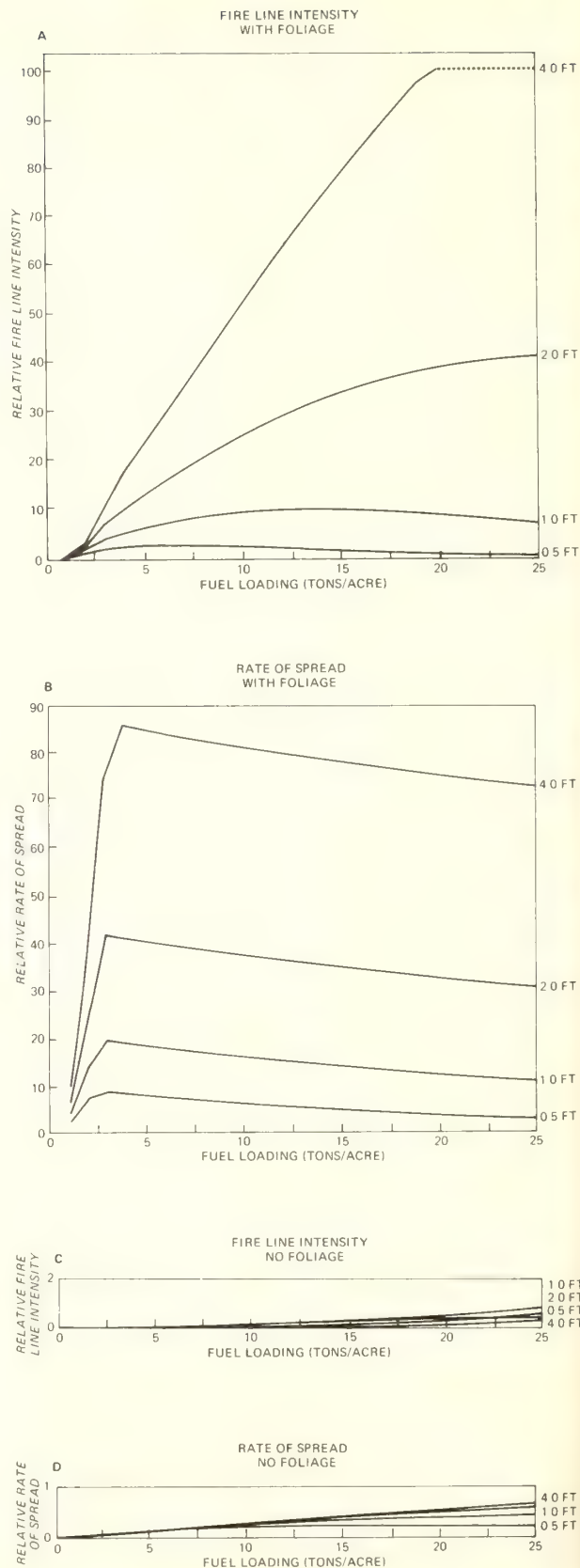


Figure 2.--Relative fire line intensities and rates of spread for red pine slash; wind = 14 mi/h; moisture content = 6 percent.

Table 1 lists the inputs needed to plot these graphs with the Rothermel fire model. Initially, the fuel inputs were sought for seven species and four particle size classes: (1) foliage; (2) fine twigs (0-1/4 inch); (3) coarse twigs (1/4-1 inch); (4) branches and tops (1-3 inches). The input values used for each slash species (by particle size class) were obtained from a variety of sources. Where available, published values were used. Otherwise, field measurements and laboratory determinations were made.

The Rothermel model predicts the forward rate of spread (ft./min.) and the intensity of the combustion reaction (BTU/ft.²/min.) of "quasi-steady-state" fires burning under conditions described by the input variables. These fire behavior predictions are for conditions that would be expected at the flaming front of a fire only. Spotting and erratic flame movement are not considered. The model's predictions are most appropriate for uniformly spaced surface fuels such as grass, dense shrubs, forest litter, and well distributed logging slash.

Traditionally, Byram's (1959) expression of fire intensity (BTU/ft./sec.), often called "fire line intensity", has been used to describe the rate of energy release on wildland fires. It is the amount of energy or heat released per unit time per unit width of the fire front. Because this value represents the total energy flowing over each foot of the fire line more accurately than Rothermel's reaction intensity, fire line intensity appears more meaningful to the practicing fuel manager. So, relative fire line intensity was graphed, along with relative forward rate of spread, to represent potential fuel hazard in northeastern

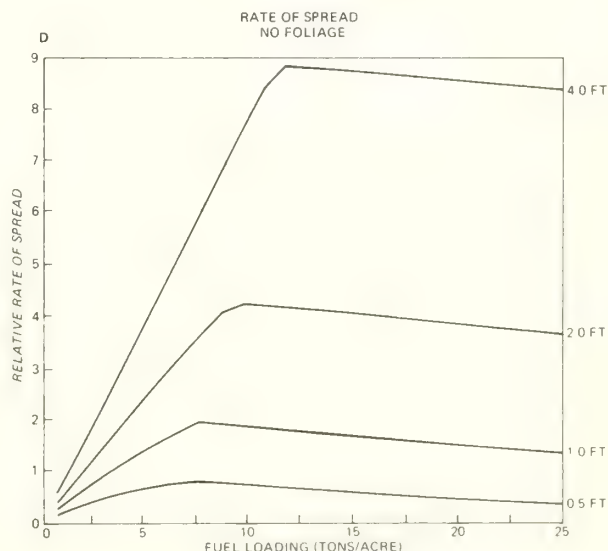
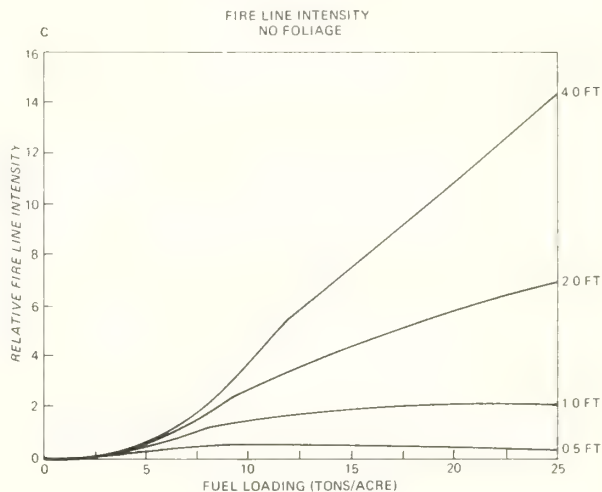
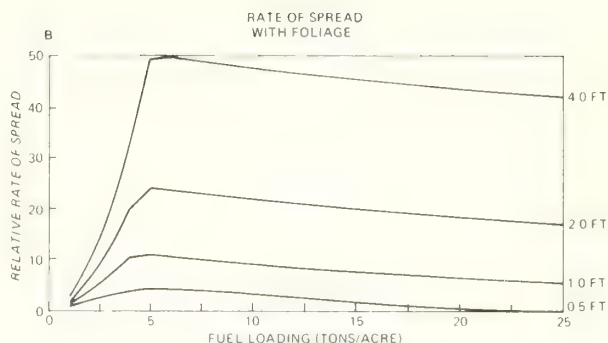
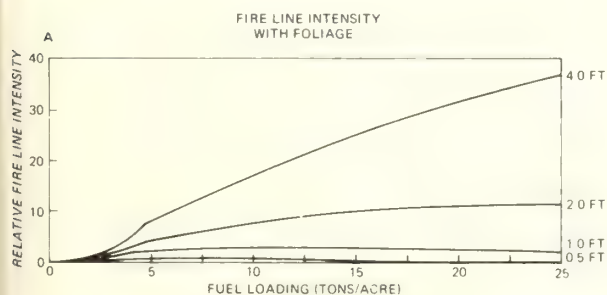


Figure 3.--Relative fire line intensities and rates of spread for balsam fir slash: wind = 14 mi/h; moisture content = 6 percent.

logging slash. Fire line intensity was determined using outputs of the Rothermel model by:

$$I = \frac{R I_R \tau}{60}$$

where: I = fire line intensity (BTU/ft./sec.)
 R = Rothermel's forward rate of spread prediction (ft./min.)
 I_R = Rothermel's reaction intensity prediction (BTU/ft.²/min.)
 τ = combustion residence time (min.)¹

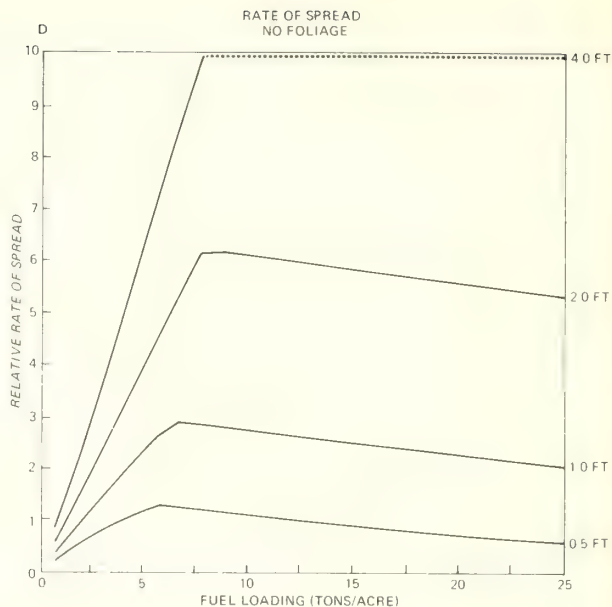
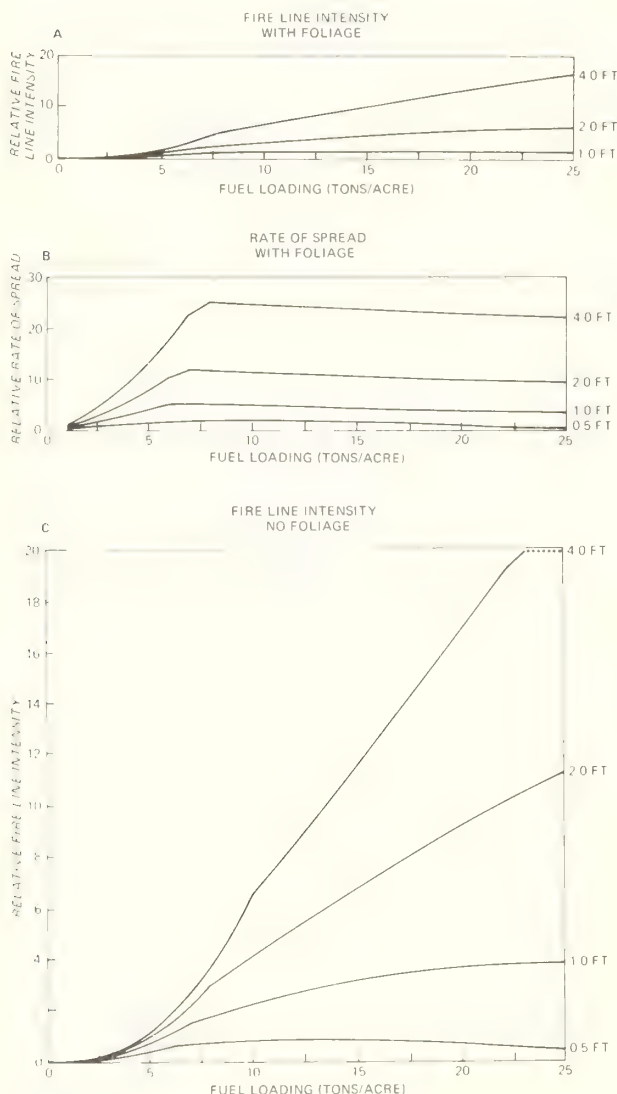


Figure 4.--Relative fire line intensities and rates of spread for black spruce slash: wind = 14 mi/h; moisture content = 6 percent.

The graphs represent fuel hazard, then, by the rate of spread and fire line intensity that the fuel would be expected to support under "average bad" weather conditions. Local weather conditions corresponding to the "very high" fire planning level were chosen to represent average bad burning conditions for any geographic locality. A series of graphs was constructed for each of the 13 different combinations of wind speed and fuel moisture content defining the very high fire planning levels on 15 National Forests comprising the Eastern Region (table 2).

To obtain open-ended, dimensionless index scales for relative hazard rating, the rate of spread and fire line intensity predictions were normalized against 5.5 ft./min. and 166.7 BTU/ft./sec., respectively. That is, the absolute predictions of rate of spread and fire intensity were divided by these values. These values were chosen so that a relative scale from 0 to 100 would encompass at least 90 percent of all realistic fire behavior situations. By eliminating actual units of measure, the

¹The residence time was derived using the relationship given by Anderson (1969). Residence time in minutes is equal to eight times the particle diameter in inches.

potential confusion associated with unfamiliar measurement units has been circumvented, possibly making the fuel hazard graphs more useful.

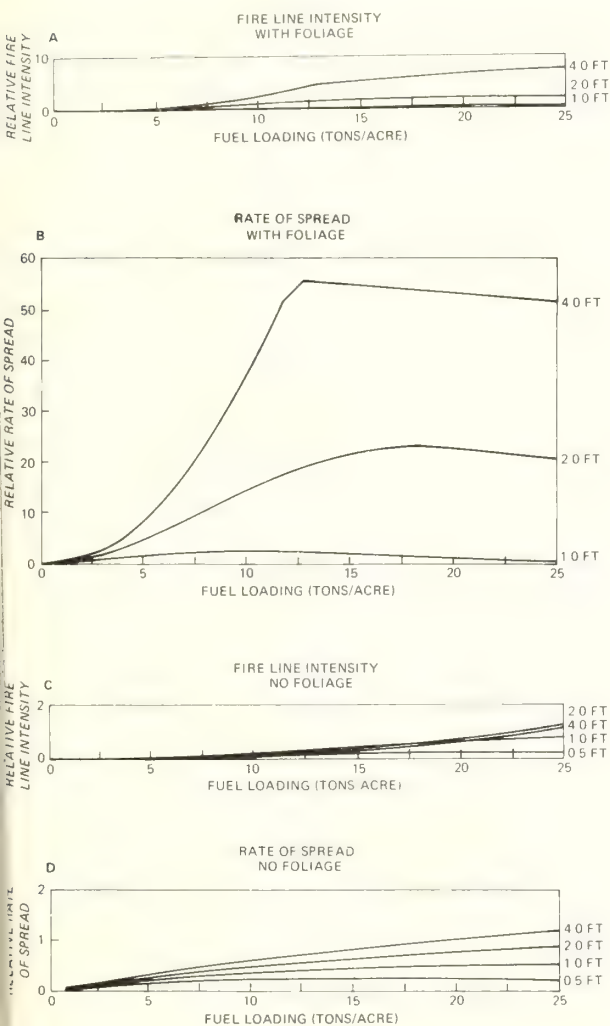


Figure 5.--Relative fire line intensities and rates of spread for aspen slash: wind = 14 mi/h; moisture content = 6 percent.

WHAT THE GRAPHS SHOW

Four graphs were plotted for each combination of species, wind speed, and fuel moisture content. They depict: (A) relative fire line intensity for slash retaining all its foliage; (B) relative

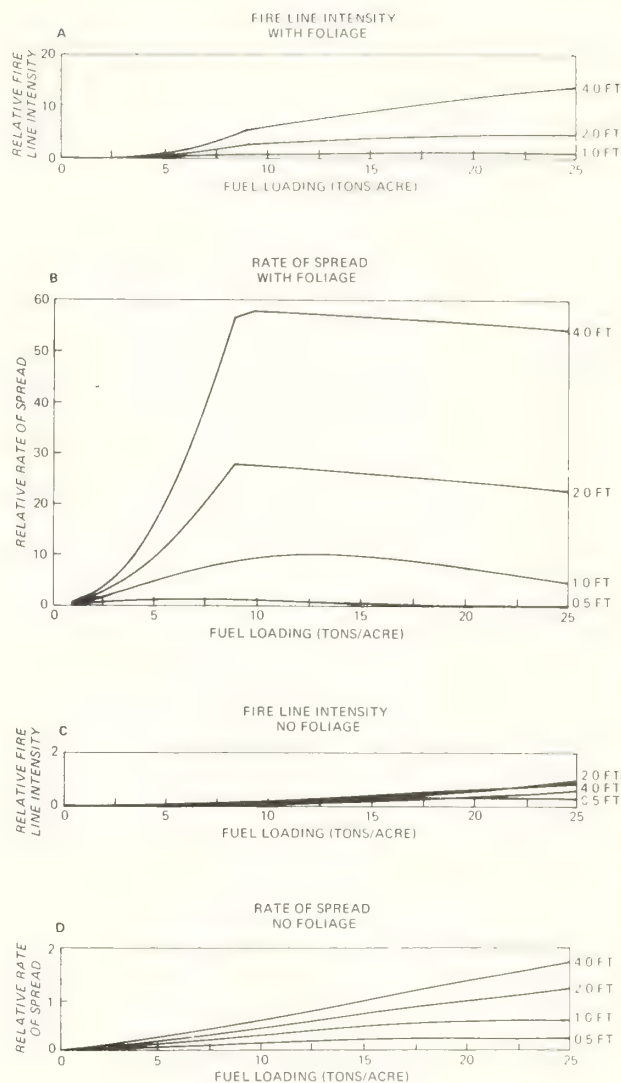


Figure 6.--Relative fire line intensities and rates of spread for paper birch slash: wind = 14 mi/h; moisture content = 6 percent.

forward rate of spread for slash retaining foliage; (C) relative fire line intensity for slash that has lost its foliage; and (D) relative forward rate of spread for slash that has lost its foliage (figs. 1-7). In all, 364 graphs were produced representing a wide variety of slash conditions and weather regimes in the northeastern United States. Of these, 28 are presented, representing 7 species of slash at only one combination of wind speed and fuel moisture content.

The species are jack pine (*Pinus banksiana* Lamb.), red pine (*Pinus resinosa* Ait.), balsam fir (*Abies balsamea* (L.) Mill.), black spruce (*Picea mariana* (Mill.) B.S.P.), quaking aspen (*Populus tremuloides* Michx.), paper birch (*Betula papyrifera* Marsh.), and mixed oaks (*Quercus* spp.). The 14 mile-per-hour wind and 6 percent fuel moisture content define the very high planning level for portions of the Allegheny, Huron-Manistee, Superior, and Wayne-Hoosier National Forests. Graphs for other combinations of wind speed and fuel moisture content can be obtained from the authors.

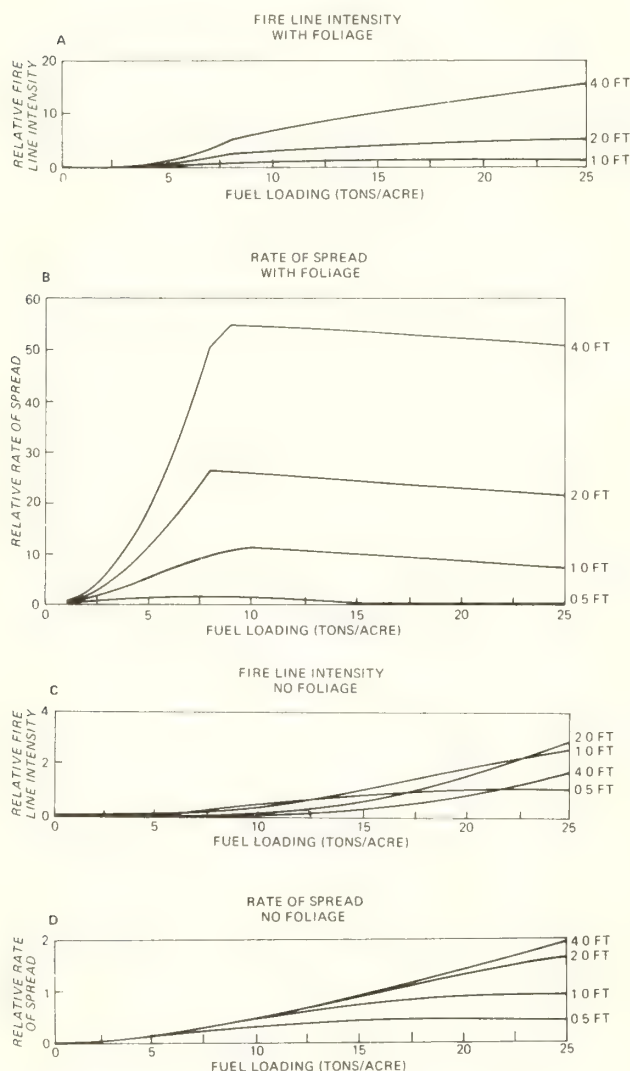


Figure 7.--Relative fire line intensities and rates of spread for oak slash: wind = 14 mi/h; moisture content = 6 percent.

Figure 1, showing relative fire line intensity and rate of spread for jack pine slash, both with and without foliage, exemplifies a single set of four fuel hazard graphs. Loadings range from 0 to 25 tons per acre, and depths of 1/2, 1, 2, and 4 feet are represented.

In figure 1A, relative fire line intensity (vertical axis) is graphed for jack pine slash, foliage attached. The horizontal axis is the loading, in tons per acre, of slash material less than 3 inches in diameter (including foliage). Material larger than 3 inches in diameter is ignored because, except for reducing maneuverability and physically supporting the finer fuels, it contributes little to fuel hazard. The vertical axis is a relative intensity scale. It relates to the amount of heat energy flowing over the fire line, and hence to the difficulty of direct attack. Also, it is open-ended; there is no upper limit to its possible values. Fires having relative intensities over 100 are infrequent, however, so extension of the axis beyond this would not be justifiable. Table 3 attempts to make these dimensionless numbers meaningful in terms of the behavior of real fires, while figure 8 shows the appearance of several experimental fires, conducted in jack pine slash by Stocks and Walker (1972), to relative fire line intensities.

Each of the four curves (the bottom one is partially obscured by the fuel loading axis) indicates relative intensity for slash, at various loadings, piled to the average depth shown at its extreme right end. Moving from left to right, each of these lines shows how fire intensity changes as more slash is packed into the same space (fixed depth). The 4-foot curve, for example, shows that fire line intensity will constantly increase as slash fuel is added to the 4-foot fuel bed. It increases from 0 at about 1 ton per acre, where fuel particles are too loosely packed to burn, to a value of 31 at 25 tons per acre. The 2-foot curve, representing slash packed twice as tightly, has a similar shape. It rises rapidly from 0 at about 1 ton per acre and begins to level off as the loading approaches 25 tons per acre. Here the relative fire line intensity is about 10.

Table 1.--Input variables for the Rothermel fire model

Input	Dimensions	Sources of Values Used
Total loading of slash material under 3" in diameter	Tons/ac.	This input is used as a continuous independent variable ranging from 0 to 25 tons per acre
Average slash depth	feet	This input is a discrete independent variable having values of .5, 1, 2, and 4 feet
Proportion of the fuel loading in each size class	dimensionless	Determined through actual data collection in Minnesota and Michigan
The ratio of fuel surface area to fuel volume by size class	ft. ⁻¹	Brown (1970), supplementary data collection
Low heat of combustion for each size class	BTU/LB	Gorham and Sanger 1967 Hough 1969 Hughes 1971 Reiners and Reiners 1970
Oven dry fuel particle density by size class	lbs/ft. ³	Byram <i>et al.</i> 1952, Wood Handbook 1955, supplementary data collection
Silica free mineral content by fuel size class	percent by weight	Hough 1969, supplementary data collection
Total mineral content by fuel size class	percent by weight	Hough 1969, supplementary data collection
Moisture content of extinction	percent by weight	Rothermel 1972
Fuel particle moisture content	percent by weight	Average "very high" planning level values for Eastern Region National Forests ¹
Wind speed	ft./min.	Average "very high" planning level values for Eastern Region National Forests ¹
Slope	percent	Fixed at zero

¹From FIRDAT (Furman and Helfman 1973).

Table 2.--Fuel moisture (FFM) and wind speeds (WDS) for high, very high, and extreme fire planning levels in the Eastern Region¹

Forest and Station	High		Very High		Extreme		Fuel Model ²
	FFM	WDS	FFM	WDS	FFM	WDS	
Allegheny Marienville	8	14	6	14	4	14	H
Chequamegon Clam Lake	7	11	6	12	4	14	H C
Chippewa Cass Lake	7	15	6	17	7	25	C
Clark Salem	6	14	5	16	4	20	E
Green Mountain Mt. Tabor	8	8	6	9	5	11	H
Hiawatha Town Lake & Moran	7	11	10	13	7	17	H C
Huron-Manistee Mio & Baldwin	9	12	6	14	6	18	C
Mark Twain Ava	5	12	5	16	4	20	E
Monongahela Marlington	8	9	7	14	6	21	H
Nicolet Laona	7	14	5	15	5	18	H C
Ottawa Watersmeet	7	13	7	15	5	19	H
Shawnee Vienna	8	12	7	18	7	22	E
Superior Ely S.C.	8	14	5	14	5	16	H C
Wayne-Moosier Athens	7	14	6	14	5	16	C I
White Mountain Conway	8	12	6	14	6	16	I E
	8	10	6	14	4	17	E
	5	8	4	10	2	13	H

¹As determined by FIRDAT (Furman and Helfman 1973).

²As described by Deeming *et al.* (1972).

The curves representing 1/2-foot and 1-foot slash depths may, at first glance, seem a bit bewildering. The 1-foot curve rises to a maximum fire line intensity just under 3 at 12-1/2 tons per acre, than begins to decline slightly as additional slash is packed into the 1-foot fuel bed. How can additional fuel result in reduced combustion intensity? Adding more fuel, when depth is held constant, creates a

more tightly packed fuel complex, reducing the availability of oxygen to fuel surfaces and altering the efficiency of heat transfer. It must be emphasized, however, that this condition seldom occurs in unmodified slash fuels and therefore the fire behavior model has not been thoroughly tested in such fuel beds. The addition of fuel will usually increase a fuel bed's depth as well as its loading.

Table 3.--*Relation of relative fire line intensity to actual fire behavior*

Relative intensity	BTU/Ft./Sec.	Fire description
.01-.02	2-3	Few forest fires have intensities this low (Byram 1959).
.1-.3	19-58	Most prescribed fires burning against the wind. Depth of the flaming zone (front to back) would be less than 1 foot and the flame length about 2 feet. Could easily step over the fire without fear of injury (Byram 1959).
.6-6	100-1,000	The section of prescribed and wild fires burning with the wind in surface fuels. At the upper end of this range, where "the roar of flames would be accompanied by occasional explosive and whistling sounds," the fire might be described as "fairly hot" (Byram 1959). Flame length would be about 9 feet and observers 30 to 40 feet from the fire would be uncomfortably warm.
12-39	2,000-6,500	Crown fires in standing pine measured by Van Wagner (1968).
63	10,500	1971 Thackary Fire in Ontario (Walker and Stocks 1972).
81	13,500	1971 Whistle Lake Fire in Ontario (Walker and Stocks 1972).
135	22,500	1967 Sundance Fire (Anderson 1968).
2-103	357-17,090	Range of observations for 24 experimental fires in jack pine slash (Stocks and Walker 1972).

Figure 9 plots fuel depth against loading of material under 3 inches for a number of slash areas measured by the author and by Muraro (1968, 1971), and shows, by dashed lines, the general range of depths that should normally be expected at various slash loadings. On this basis, the loading for unmodified slash averaging 1 foot in depth would seldom exceed 11 or 12 tons per acre. Of course, by treating slash mechanically, it is possible to artificially create conditions beyond these limits.

Figure 1B is similar to figure 1A. The fuel loading axes (horizontal) are

identical, and the 4 curves represent the same fuel depths. The vertical axis, representing relative forward rate of fire spread, again has no units of measurement.

The sharp change in the rate-of-spread curves at a fuel loading of about 5 tons per acre is where the wind becomes fully effective in driving the fire. At loadings below this point, the effect of wind on fire spread is limited by the intensity of the fire. The fact that the spread rate drops off at loadings above this point doesn't necessarily indicate that more fuel results in slower spread. This

contradicts experience. Remember, each of the curves shows the effect of packing more fuel into the *same space*. Additional fuel can reduce the rate of spread by obstructing convective and radiant transfer of heat. Again, however, higher fuel loadings are generally accompanied by deeper fuel beds--with the overall effect of increased rate of spread.

a



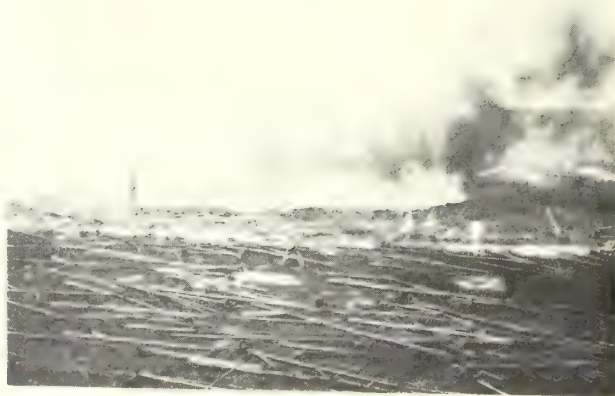
b



c



d



e



f



Figure 8.--Visual appearance of experimental fires in jack pine slash. Measured relative fire line intensities were (a) 2, (b) 5, (c) 8, (d) 25, (e) 57, and (f) 103. Photographs and intensity measurements were provided by Brian Stocks and John Walker (Stocks and Walker 1972).

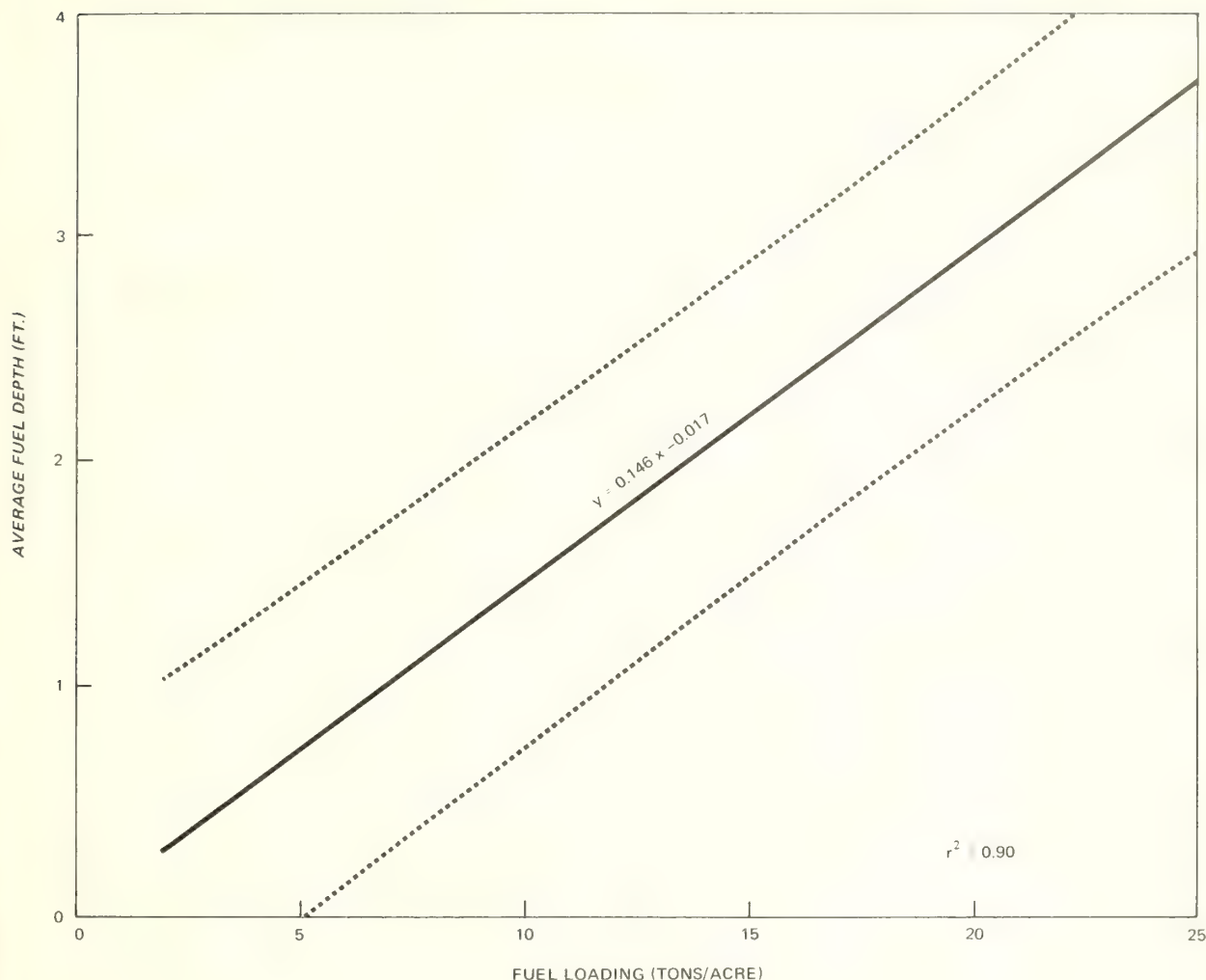


Figure 9,--Regression of fuel depth on loading for unmodified slash material under 3 inches in diameter. The regression involves two data sources: 1) field measurements in a tornado blowdown near Virginia, Minnesota, and 2) published data extracted from Muraro (1968, 1971). The dashed lines depict the 95% confidence interval for a single prediction by the equation.

In figures 1C and 1D, relative fire line intensity and rate of spread are graphed for jack pine slash after all foliage had dropped. Note that the scales of the vertical axes are different than those in figures 1A and 1B. The vast reduction in fuel hazard when foliage falls makes the scale change necessary to allow visual separation of the curves. Without this modification, the lines would be difficult to distinguish from

one another. Scale should be closely observed when making comparisons of fuel hazard for slash with and without foliage.

HOW TO USE THE GRAPHS

The greatest potential for this system is that slash hazard can be predicted before cutting begins, as well as after its completion. To estimate fuel hazard for logging slash, all that is

needed is knowledge of the condition of foliage, loading of slash material less than 3 inches in diameter in tons per acre, average slash depth in feet, and the wind speed and fuel moisture content representing the local "very high" fire planning level.

Visual determination of the condition of foliage and average slash depth should be adequate. Because the fuel hazard prediction is sensitive to changes in depth, average slash depth should be estimated conscientiously. Depending on the accuracy desired, slash loading can either be estimated or measured in the field. If the slash has already been created, and time is available to take some measurements, Roussopoulos and Johnson (1973) explain a field sampling procedure that can be done in northeastern slash with little time and effort. Fahnestock (1960) developed a way to estimate the weight of slash before logging for nine western species. A similar method can be used in the east. To predict slash loading (in tons per acre), multiply the basal area to be harvested from each D.B.H. class by the corresponding value from table 4² and sum these products for all classes in the harvest.

After the condition of foliage, slash depth, and slash loading has been determined or predicted, the fire-intensity and rate-of-spread graphs can be used to estimate fuel hazard. An example may help illustrate the use of these graphs in fuel management decisionmaking. Assume that the local "very high" planning level corresponds to the wind speed and fuel moisture content in figures 1-7. Also, assume that a jack pine stand has been clear cut producing about 10 tons per acre of slash material less than 3 inches in diameter, uniformly distributed at an average depth of about 2 feet. Figure 1 can be helpful in deciding how this slash should be managed by providing answers to the questions asked in the Introduction.

What fuel hazard can be handled adequately through normal fire control operations? This can be expressed as the relative intensity and rate of spread for the National Fire Danger Rating System (Deeming *et al.* 1972) fuel model used for fire control planning in any forest pro-

tection unit. Because fire control efforts are based on the expected behavior of fires burning in a chosen fuel model, this model can reasonably be used as a standard of fuel hazard against which fuel hazard on specific sites can be compared. Table 5 shows the relative rates of spread and fire line intensities for the nine fuel models when the wind speed is 14 miles per hour and fuel moisture content is 6 percent. For example, if fuel model H has been chosen for the protection unit in which the jack pine stand was harvested, the planning level fuel hazard can be represented by a *relative* fire line intensity of 0.6 (97 BTU/ft./sec.) and a *relative* rate of spread of 4.3 (24 ch./hr.). Either slash treatment or increased protection should be considered then, if the ratings for the post-cutting slash exceed these values.

What is the post-cutting hazard?

Assuming that the foliage is retained on the slash, the post-cutting hazard attributable to the slash can be determined from figures 1A and 1B. In figure 1A, at a slash loading of 10 tons per acre, a horizontal line drawn from the 2-foot depth curve cuts the fire-line-intensity axis at about 7, far above the 0.6 determined for fuel model H. The relative rate of spread, from figure 1B, is about 18, again much larger than 4.3 for fuel model H. Both post-cutting hazard components clearly exceed those for the "standard" planning level hazard, calling for some form of slash treatment or increased protection.

What treatment alternatives are feasible? Because the Rothermel model can be applied only to uniformly distributed fuels, the graphs cannot be used to evaluate efforts to interrupt fuel continuity, such as creating fuel breaks and windrows. They may be helpful, on the other hand, in deciding among alternative broadcast treatment methods such as lopping and scattering, prescribed burning, and crushing or chopping. One alternative is simply to increase protection of the slash area until, through natural breakdown, the fuel hazard is reduced to a tolerable level. The hazard of jack pine slash, of course, is highest when the needles are still attached. As needles dry and fall, a process taking up to 4 years (Williams 1955), hazard slowly diminishes. Figures 1C and 1D, the pair

²Loomis, Robert M. 1973. Unpublished secondary analysis of published data. (On file at North Central Forest Experiment Station, East Lansing, Michigan.)

of graphs for jack pine slash without foliage, make this evident. For the above example, figure 1C indicates a relative intensity of 0.5, while the relative rate of spread in figure 1D is about 1.2. Both are below the planning level values, so increased protection until

the foliage drops seems a feasible approach. In this case, the overall fuel hazard is underestimated because the fire would be spreading mainly in the litter, rather than in the slash itself. The graphs indicate fire behavior *in the slash*. Nevertheless, the values from the graphs

Table 4.--Tree crown weights by species and d.b.h. per square foot of basal area in tons¹

D.B.H. (inches)	Shortleaf pine	Red pine (white pine) ²	Jack pine	White spruce (black spruce)	Balsam fir (white cedar, hemlock)	Aspen (larch)	Yellow-poplar (other "soft" hardwoods)	"Hardwoods" (all "hard" hardwoods)
1	0.16	1.01	0.15	0.13	0.13	0.20 (.19)	0.26 (.25)	0.32 (.29)
2	.20	.35	.16	.17	.18	.15 (.14)	.34 (.33)	.42 (.40)
3	.16	.18	.15	.17	.16	.11 (.10)	.37 (.36)	.35 (.33)
4	.11	.13	.14	.14	.12	.09 (.08)	.23 (.22)	.25 (.23)
5	.09	.11	.15	.13	.12	.08 (.07)	.17 (.16)	.22 (.20)
6	.07	.10	.15	.14	.12	.07 (.06)	.13 (.12)	.20 (.18)
7	.09	.10	.15	.15	.14	.07 (.06)	.11 (.10)	.19 (.17)
8	.09	.10	.15	.16	.15	.06 (.05)	.10 (.09)	.18 (.16)
9	.09	.10	.15	.17	.17	.06 (.05)	.09 (.08)	.18 (.16)
10	.09	.11	.15	.18	.19	.06 (.05)	.08 (.07)	.18 (.16)
11	.09	.12	.15	.19	.20	.05 (.04)	.07 (.06)	.17 (.16)
12	.10	.14	.15	.20	.22	.05 (.04)	.07 (.06)	.17 (.16)
13	.10	.16	.15	.22	.25	.05 (.04)	.06 (.05)	.17 (.16)
14	.11	.18	.15	.23	.26	.05 (.04)	.06 (.05)	.17 (.16)
15	.11	.22	.15	.24	.28	.05 (.04)	.06 (.05)	.17 (.16)
16							.06 (.05)	.17 (.16)
17							.06 (.05)	.17 (.16)
18							.06 (.05)	.17 (.16)
19							.05 (.04)	.18 (.17)
20							.05 (.04)	.18 (.17)
21							.05 (.04)	.18 (.17)
22							.05 (.04)	.18 (.17)
23							.05 (.04)	.19 (.18)
24							.05 (.04)	.19 (.18)

¹Tree crown weight includes stemwood less than 3 inches in diameter, branchwood, and foliage; numbers in parentheses do not include foliage.

²Species in parentheses are additional species to which table may be applied.

NOTE: The larger hardwoods include branchwood larger than 3.0 inches in diameter. All branchwood included. Dead branchwood included for jack pine, white spruce, and balsam fir.

indicate the relative significance of the slash itself, in terms of fire behavior, even when superimposed on a litter substrate.

Table 5.--Relative rates of spread and fire line intensities for the NFDRS fuel models with a wind velocity of 14 miles per hour and fuel moisture content of 6 percent

NFDRS Fuel Model	Relative Rate of Spread	Relative Fire Line Intensity
A	79.3	8.4
B	48.8	27.6
C	47.8	7.1
D	23.2	5.5
E	10.6	1.5
F	9.2	2.1
G	9.0	4.7
H	4.3	0.6
I	20.1	15.9

If 3 or 4 years of increased protection are not logistically or economically desirable, some means of fuel treatment should be considered. One alternative is prescribed fire. Even the most modest fire will at least remove the foliage, which would reduce the hazard to an acceptable level in the example situation.

The effectiveness of depth reduction, another alternative, can be clearly seen in figures 1A and 1B. If, by lopping and scattering, roller-chopping, or some mechanical means of crushing, the average slash depth could be reduced to 1/2 foot, the relative intensity would drop to about 0.6 and the relative rate of spread to about 3, both acceptable.

The above procedures are summarized in Figure 10. In choosing among feasible alternatives, of course, silvicultural and environmental implications should be considered as well as hazard reduction effectiveness. What, for example, is the possible influence of slash compaction on regeneration success? On these matters there is no substitute for professional expertise.

How should priorities be established for different areas? In addition to the severity of the fuel hazard itself, the priorities should be based on local risk, surrounding resource values, silvicultural significance, accessibility, juxtaposition of natural barriers, environmental impact, and logistics. When these other factors are nearly equal, however, as is often the case, hazard ratings can help order priorities for the areas needing treatment. The relative fire line intensity and rate of spread can be used to establish priorities. Then areas can be treated in order of decreasing hazard until time, funding, or other limiting resources are exhausted.

CONCLUSION

The procedure presented and discussed here can reduce the need for managerial guesswork. The graphs were constructed using a mathematical model based strictly on laboratory experiments, and a number of addition assumptions and simplifications were incorporated into the graphic displays. It is assumed that only uniformly distributed slash is burning, that the fire has reached an equilibrium state, that is, it is not an accelerating fire, and that fuels of all sizes have identical moisture contents. These assumptions are somewhat less than realistic, but not overly restrictive. Even more important, users must realize that fuel management is only one aspect of land management. Costs and benefits of alternative fuel management strategies should be weighed, not only in terms of resulting fuel hazards, but also relative to overall land management objectives. Still, if used properly, with regard for inherent limitations, these hazard rating graphs can be valuable decisionmaking tools. If nothing else, they can provide concrete justification for projects already underway. Beyond this, they quantify fuel hazard in a way meaningful to any manager, regardless of his level of experience. Alternative fuel management practices can be evaluated and compared objectively before they are actually attempted. Fuel hazard potentially resulting from planned forest management projects can be anticipated, and operations that cannot economically provide adequate fuel treatment to meet protection standards can be aborted before resource values are jeopardized.

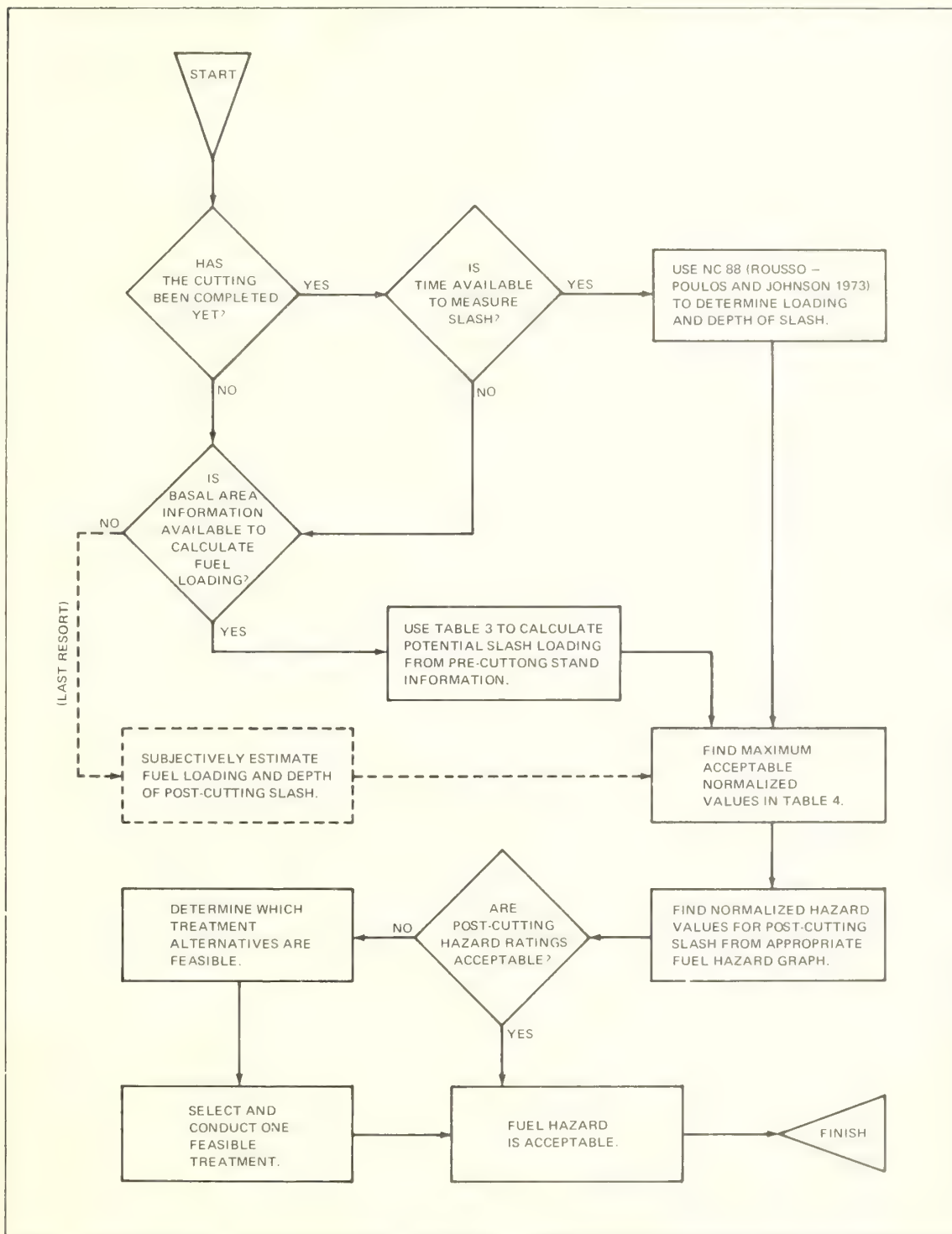


Figure 10.--Flow chart illustrating the use of fuel hazard graphs in slash management decision making.

As the technology of forest fire management steadily becomes more sophisticated and effective, the human or managerial aspects must keep pace. Advance planning and objective decision-making will be the key to successful management. The approach suggested here is a step in that direction.

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Roussopoulos, Peter J., and Von J. Johnson.

1975. Help in making fuel management decisions.

North Cent. For. Exp. Stn., St. Paul, Minn.

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OXFORD: 431.2:432.16:33(74/77) KEY WORDS: fuel hazard, logging debris, fuel treatment, fire behavior, fire management.

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Anatomy And Dry Weight Yields Of Two *Populus* Clones Grown Under Intensive Culture



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ANATOMY AND DRY WEIGHT YIELDS OF TWO *POPULUS* CLONES GROWN UNDER INTENSIVE CULTURE

John B. Crist and David H. Dawson

Considerable interest has been generated in utilizing the total wood and perhaps the bark produced by young woody species grown under short rotations for pulp or particleboard production. Representatives of the industry feel that rotations must be shortened and yields of high-quality materials substantially increased if expenditures for woodland improvement are to be competitive with other investment alternatives. Extremely intensive silviculture, such as has been demonstrated with camellia in the southeastern United States using the corn-silage system (McAlpine *et al.* 1966), may very well be economically feasible (Dutrow 1971). Continuing research and development effort already has demonstrated that kenaf (*Hibiscus cannabinus*) can be grown as a high intensity, short rotation (annual) crop on high-quality land (White *et al.* 1970).

There is considerable biological evidence that growing large trees over long rotations may not be the most efficient system for capturing the solar energy available or quickly and completely occupying a site. For example, Leak (1970) pointed out that conventional timber production accounts for a very minute proportion--0.1 to 0.2 percent of the net solar energy that enters into a northern hardwood stand. Daniels (1956) in contrast, reported that photosynthesis in a laboratory may attain efficiencies of up to 35 percent under optimum conditions. Implied in these findings is that traditional forest management has been almost exclusively concerned with less than 1 percent of the solar energy entering the forests we manage. For maximum production

of woody fiber, it is apparent that foresters need to understand how to utilize more of the remaining 99+ percent.

Recently the USDA Forest Service's North Central Forest Experiment Station in Rhinelander, Wisconsin, launched Program Maximum Yield, in which a systems approach is being taken to develop the most efficient and economic method for producing fiber from woody plants. Basic research input is being collated from specialists in the fields of physiology, genetics, engineering, utilization, and economics under this program. As described by Dawson and Hutchinson (1972), it is hoped that the results will enable segments of the industry in the North Central Region to assume a more viable role in helping to meet the expanding need for pulpwood. An early study in Program Maximum Yield, reported here, was made to determine the dry weight yield and quality of material produced by two *Populus* hybrids grown in an agronomic mode for 2 yr under intensive cultivation near optimum moisture and nutrient levels at three plant spacing densities.

THE PLANT MATERIAL AND RESEARCH METHODS

The two clones chosen for the study were *Populus* "Tristis #1" (*Populus balsamifera* L. x *P. tristis* Fisch.) and "Northwest" poplar (*Populus deltoides* Marsh. var. *occidentalis* Rydb. x *P. balsamifera* L.). Both clones propagated easily and were known to be hardy in the North Central States as well as to have manifested different crown and

branch architecture in conventional spacings. Both were available in quantity from the Forest Nursery Station at Indian Head, Saskatchewan, where they have been selected and tested for years (Cram 1960).

Plantings were spaced at three relatively high densities (9 in. by 9 in., 12 in. by 12 in., and 24 in. by 24 in.) because density-clone interactions had to be determined early in the rotation period. Dominant cuttings of each of the two clones were planted during the summer of 1970 at each of these three densities in three 16 ft by 16 ft irrigated plots in three replications using a randomized block design. By the fall of 1970, most of the cuttings had rooted; where fail spots occurred, replacements were made using cuttings that had been rooted in adjacent beds.

Throughout the first full growing season--the spring and summer of 1971--nutrients were applied frequently to the soil to ensure that nutrients in the plants were maintained at slightly above the critical level (i.e., the concentration of an element in the leaves at which plant growth begins to decline). Moisture levels were maintained at 75 to 90 percent field capacity.

Near the end of the 1971 growing season, all aerial portions of trees from 2 by 6 ft subplots were harvested. This material was measured, separated by components, oven-dried at 70°C until equilibrium was reached, and then weighed.

Anatomical characteristics of the two clones were measured as part of a screening process to determine the relative suitability of various candidates for fiber production in a maximum yield system.

Three stems of harvested plants (replications) were taken from each of the three planting densities for each of the two clones and examined. Segments of each stem were removed from near the base, middle, and tip. Microtomed sections were cut from these segments and photomicrographed. The photomicrographs were projected onto a screen containing a grid from which countings were made to calculate the percent composition of vessels and of bark fibers. The diameters of the vessels and of the bark fiber bundles also were measured using the calibrated projections. Specific gravities of intact stem segments were determined using the water immersion method. The same method was used to determine individual specific gravities for the wood and for the bark after the segments had been dissected and the pith had been removed from the wood. Fiber, vessel, and bark-fiber lengths were obtained from calibrated microscopic projections of tissues that had been macerated using peracetic acid. Broken or cut cells were not measured. Data were analyzed using a 4-way analysis of variance for each of the 10 anatomical characteristics.

RESULTS AND DISCUSSION

Table 1 documents that considerable tonnage of wood and bark can be produced by

Table 1.--Dry weight by components of *Populus "Tristis #1"* and *Populus "Northwest"*¹

(In tons/acre)

POPULUS "TRISTIS #1"												
Planting:	Totals					Stems			Branches			
density :	Tree	Wood	Bark	Tips	Leaves	Total	Wood	Bark	Total	Wood	Bark	
(in.) :												
9 by 9	12.25	6.29(51) ²	2.94(24)	0.11(1)	2.91(24)	6.61(53)	4.74(38)	1.86(15)	2.63(21)	1.55(12)	1.08(8)	
12 by 12	9.33	4.01(42)	2.45(26)	.12(2)	2.75(29)	4.71(50)	3.16(33)	1.54(17)	1.76(19)	.85(9)	.91(10)	
24 by 24	3.86	1.58(44)	.97(25)	.05(1)	1.26(32)	1.67(43)	1.11(28)	.56(14)	.89(23)	.47(12)	.41(11)	
POPULUS "NORTHWEST"												
9 by 9	6.38	2.79(44)	1.65(25)	0.15(2)	1.79(28)	3.98(62)	2.59(40)	1.39(21)	0.46(7)	0.20(3)	0.26(4)	
12 by 12	5.70	2.09(37)	1.76(31)	.11(1)	1.74(31)	2.72(48)	1.82(32)	.90(16)	1.13(19)	.27(4)	.86(15)	
24 by 24	2.02	.57(28)	.47(23)	.05(2)	.93(46)	.71(35)	.41(20)	.30(14)	.33(16)	.16(7)	.17(8)	

¹One-yr-old material from rooted cuttings.

²Percent of total tree weight in parenthesis.

very dense stands of young trees. Sprouts from the 2-yr-old rootstock of *Populus* "Tristis #1" planted at the 9 in. by 9 in. density produced the equivalent of over 6 tons of wood and almost 3 tons of bark/acre/year at 9 in. by 9 in. planting density. The *Populus* "Northwest" sprouts were only slightly better than half as productive.

However, sprouts from both clones yielded greater tonnages of wood and bark than did "total tree harvested" in natural aspen stands on good sites in the Lake States that yielded between 1 and 2 tons/acre/year (Einspahr and Benson 1970, Benson and Einspahr 1972).

Table 2 shows differences in the 10 measured anatomical characteristics between the 2 clones. The means presented were obtained by averaging data for all replications, planting densities, and stem sampling heights for each clone. Differences or patterns attributable to planting density or sampling height are included in the following discussion.

The specific gravity of *P. "Tristis #1"* wood (without pith) was much higher

than that of *P. "Northwest"* wood (Table 2); yet the values for both clones were within the wide range of specific gravities reported for *Populus* species (Isenberg 1951, Valentine 1962, Wilde and Paul 1959). The specific gravities of both clones increased as planting densities decreased. However, specific gravity progressively decreased as stem height increased in *P. "Tristis #1"*; just the opposite was found in *P. "Northwest."*

The fibers of *P. "Tristis #1"* were slightly shorter than those of *P. "Northwest."* Although fibers from both clones were short, their lengths are comparable to the fibers of other young *Populus* species and hybrids (Cech *et al.* 1960, Kennedy and Smith 1959). As would be expected, the fibers of both clones decreased in length as stem height increased.

Stems grown at the 12 in. by 12 in. density had slightly longer fibers than those grown at the 9 in. by 9 in. density. This observation might be attributed to differences in crown geometry and morphology, which enabled larger amounts of photosynthate to be distributed to the stem

Table 2.--Comparison of anatomical characteristics of two hybrid *Populus* clones

Measured characteristics	<i>Populus</i> "Tristis #1": mean ¹	<i>Populus</i> "Northwest": mean ¹	Difference between means ²
Wood (without pith)			
sp. gr.	0.402	0.338	** ³
Fiber length (mm)	.560	.574	* ⁴
Vessel length (mm)	.276	.247	**
Vessel diameter (mm)	.040	.039	--
Vessel composition of wood (percent)	19.33	30.12	**
Bark fiber length (mm)	1.066	1.010	**
Bark fiber composition of bark (percent)	9.42	11.52	**
Bark fiber bundle diameter (mm)	.146	.118	**
Bark sp. gr.	.397	.370	--
Intact stem segment sp. gr.	.367	.324	**

¹Averaged over all planting densities, replications, and stem sampling heights.

²Variation due to planting density, replications, and stem sampling heights removed by ANOVA.

³Denotes significant difference at the 99 percent confidence level.

⁴Denotes significant difference at the 95 percent confidence level.

for accelerating fiber growth in stems grown at the 12 in. by 12 in. planting density. However, sprouts grown at both the 9 in. by 9 in. and the 12 in. by 12 in. densities had fibers that were considerably longer than those grown at the 24 in. by 24 in. density.

The vessels of *P. "Tristis #1"* were considerably longer than those of *P. "Northwest,"* but the vessels of both clones were considerably shorter than vessels in older *Populus* (Panshin *et al.* 1964). Their lengths decreased as planting density decreased. The diameters of the vessels from both clones were similar. Generally, vessels near the top of the stem were considerably smaller in diameter than those from the middle or bottom of the stem.

The greatest difference in the wood anatomy of the two clones was in vessel

composition (fig. 1). Based on a percentage of cross sectional area, the wood of *P. "Tristis #1"* was composed of approximately 19 percent vessels as compared to 30 percent in the wood of *P. "Northwest."* This probably accounts for the lower specific gravity of *P. "Northwest"* wood.

Utilization of material produced on short rotations might include bark. Bark fibers would probably be the greatest contributors of all bark-cell types to pulp yields and properties. The bark fibers of the clone *P. "Tristis #1"* were longer than those of *P. "Northwest"* but fibers of both averaged slightly greater than 1 mm in length, which is almost the same as the length of bark fibers found in aspen (Chang 1954, Hossfeld and Kaufert 1957). If bark is included in pulp, the long fibers should enhance strength properties because the bark fibers from both

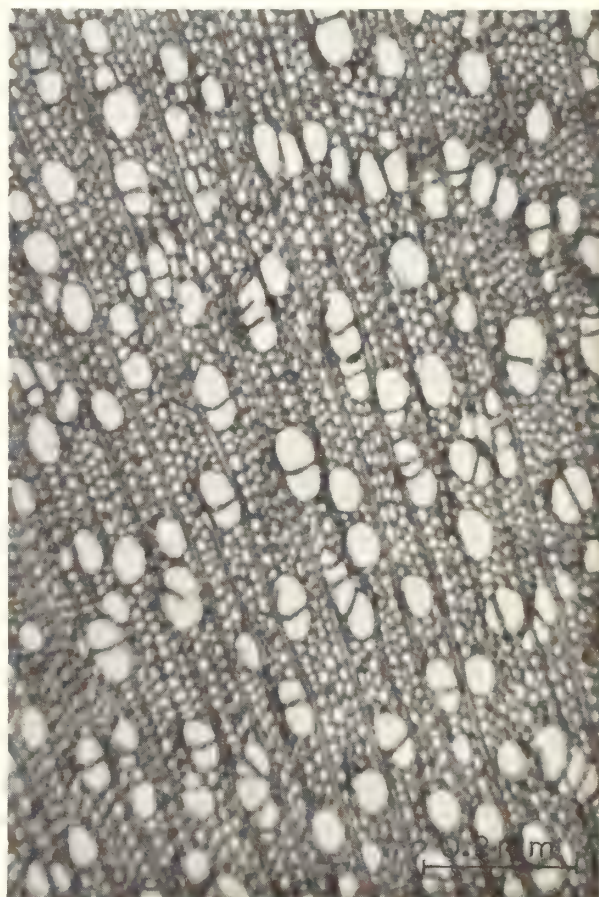
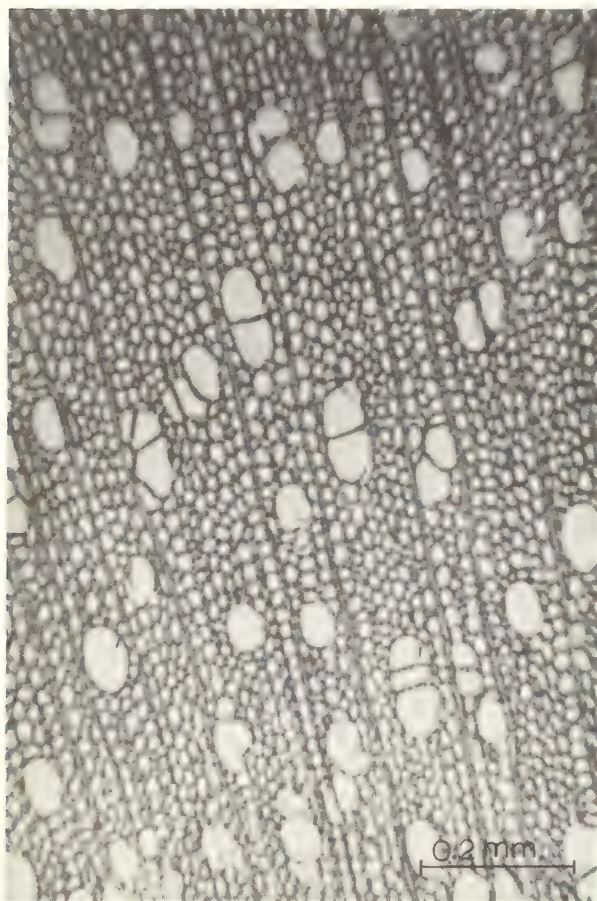


Figure 1.--Photomicrographs showing *Populus "Tristis #1"* (left) had a lower percentage of vessels than *P. "Northwest"* (right).

clones were nearly twice the length of the wood fibers.

The bark of *P. "Northwest"* had a significantly greater percentage of fiber than did that of *P. "Tristis #1,"* but both clones averaged approximately 10 percent fiber based on a percentage of cross sectional area. Bark fibers were arranged tangentially in bundles that had an approximate average diameter of 0.13 mm. No brachysclereids, commonly called "stone cells," were noticed in the bark of either clone. Apparently this cell type had not yet formed in these young stems as has been reported in other *Populus* species (Chang 1954). Difficulties in papermaking attributed to stone cells could be avoided if stems were harvested before stone cells formed.

In *P. "Tristis #1"* the specific gravity of the bark was only slightly lower than that of the wood. In *P. "Northwest"* the specific gravity of the bark was much greater than that of the wood but less than the specific gravity of the bark in *P. "Tristis #1."* The bark of both clones increased in specific gravity as stem height increased.

The specific gravities of undissected stem segments for both clones were lower than the specific gravities of their respective bark and wood. This pattern reflects the large amount and influence of pith in these small stems.

SUMMARY

Two selected *Populus* clones grown under short rotations and dense spacings produced yields averaging as much or more than recorded yields of aspen stands native to the North Central Region in the United States. The differences in yields between the two clones grown at three planting densities illustrate that the selection of genetic material and the cultured regime under which a species is grown are significant factors that must be determined in maximum yield systems specifically for the species used. Nearly all wood-quality characteristics (specific gravity, fiber length, vessel length, and vessel composition) varied significantly between clones, but most characteristics were well within the ranges reported for *Populus* pulpwood.

Of apparently great economic or practical significance is that the bark of both clones averaged approximately 10 percent fiber and that these fibers were considerably longer than the wood fibers. Moreover, no stone cells were observed in the bark of either clone. Because of the high proportion of bark weight to wood weight and additional costs of bark separation, these findings would imply that the possibilities of profitable bark usage were good. The conclusions derived should not be extrapolated to more extensive systems or immediate application on a large scale. However, they do point out that more comprehensive research on maximum fiber yield-short rotation research should be productive.

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OXFORD: 232.13:811. KEY WORDS: clonal differences, genetics, maximum yields, fiber yields.

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Nature is beautiful...leave only your footprints.

WOOD AND BARK PERCENTAGES AND MOISTURE CONTENTS OF MINNESOTA PULPWOOD SPECIES



Richard M. Marden, David C. Lothner,
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CONTENTS

Application	1
Proportion of Bark by Cubic Foot Volume	1
Dry Bark and Wood, and Moisture as a Percentage of Total Green Weight.	1
Moisture Contents of Wood and Bark on an Owendry Basis.	2
Documentation	6
Study Methods	6
Analysis.	6
Moisture Content Differences Within the Pulpwood Stick.	6
Literature Cited.	7

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WOOD AND BARK PERCENTAGES AND MOISTURE CONTENTS OF MINNESOTA PULPWOOD SPECIES

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APPLICATION

Bark has been an undesirable by-product and usually has been burned as waste or dumped as landfill--both expensive means of disposal. Recently, however, confronted with environmental concerns, the energy crisis, and a threatening fiber shortage, wood using industries have made use of bark primarily as fuel.

Those individuals involved in the round-wood market will need data on certain properties of both bark and wood as the use of bark increases. Some will need such data because weight scaling is replacing volumetric scaling in the market.

Proportion of Bark by Cubic Foot Volume

For weight scaling, it helps to know what proportion of the rough volume (wood plus bark) is bark as follows:

Species	Proportion of bark
Jack pine	6.3
<i>Pinus banksiana</i> Lamb.	(5.6 to 7.0) ¹
Black spruce	7.2
<i>Picea mariana</i> (Mill.) B.S.P.	(6.6 to 7.8)
Elmsam fir	10.7
<i>Abies balsamea</i> (L.) Mill.	(10.1 to 11.2)
Whitebark aspen	11.8
<i>Populus tremuloides</i> Michx.	(11.4 to 12.1)
Elmsam poplar	17.5
<i>Populus balsamifera</i> L.	(15.6 to 19.4)

¹Calculated at a 95 percent confidence interval, which indicates that authors can be 95 percent certain that the values within the parentheses include the true mean.

When this is known, the solid wood volume of pulpwood can be calculated from the rough wood volume. Furthermore it is possible to estimate a conversion factor (pounds of wood and bark per cubic foot of wood) that can be used to develop basic data for weight scaling pulpwood (Lothner, Marden, and Kallio 1974).

These data can also be used to estimate the amount of bark for use as a product or fuel that can be realized from a specified volume of rough wood. Also, the availability of this plus other information on bark weights and moisture contents can be used to develop specifications for boilers in which bark is to be used for fuel.

Dry Bark and Wood, and Moisture as a Percentage of Total Green Weight

In weight scaling, for example, if the green weight of rough wood is known, estimates can be made of dry wood and/or dry bark available for a species or process. If bark is to be used for fuel, the dry weight of bark should be determined since this value is directly related to fuel recovery. The green weight of material also has a bearing on transportation and processing costs.

The values in table 1, except for black spruce, are based on samples collected throughout a complete year. Although these values only indicate seasonal changes, there are monthly changes within a season. However, the sample sizes for any month or season for all species except aspen shown in table 1 were too small to give statistically reliable results. The monthly values for aspen are presented separately in table 2.

Table 1.--Mean seasonal and annual oven-dry weight of wood, oven-dry weight of bark, and moisture weight as percentages of total green wood-bark weights

Table 1.

Species	Period	Basis	Wood	Bark	Moisture
		No. of Loads	Percent	Percent	Percent
Black spruce ¹	Winter	82	53.1 (52.3-53.9) ²	5.1 (5.0-5.3)	41.8 (41.0-42.5)
Jack pine	Summer	19	50.8 (48.5-53.1)	3.9 (3.4-4.4)	45.3 (43.0-47.6)
	Winter	13	49.6 (47.0-52.2)	3.8 (3.3-4.2)	46.6 (44.1-49.1)
	Annual	32	50.3 (48.7-52.0)	3.9 (3.5-4.2)	45.8 (44.2-47.5)
Aspen	Summer	132	46.7 (46.1-47.3)	9.1 (8.8-9.4)	44.2 (43.7-44.8)
	Winter	107	40.8 (40.4-41.1)	8.6 (8.3-8.9)	50.6 (50.3-51.0)
	Annual	239	44.1 (43.5-44.6)	8.8 (8.6-9.1)	47.1 (46.6-47.6)
Balsam poplar	Summer	20	38.0 (36.8-39.2)	7.1 (6.5-7.6)	54.9 (53.8-56.0)
	Winter	22	36.0 (35.1-36.8)	8.1 (7.1-9.2)	55.9 (54.7-57.1)
	Annual	42	37.0 (36.2-37.7)	7.6 (7.0-8.2)	55.4 (54.6-56.2)
Balsam fir	Summer	18	34.9 (33.8-35.9)	6.3 (5.7-6.9)	58.8 (57.7-60.1)
	Winter	38	34.6 (33.8-35.4)	6.1 (5.8-6.4)	59.3 (58.3-60.3)
	Annual	56	34.7 (34.1-35.3)	6.2 (5.8-6.5)	59.1 (58.4-59.9)

¹ Black spruce was sampled during January, February, and March.

² Calculated at a 95 percent confidence interval, which indicates that authors can be 95 percent certain that values within the parentheses include the true mean.

Moisture Contents of Wood and Bark on an Oven-dry Basis

The moisture content of wood or bark also can be expressed as the weight of water in the material in terms of a percentage of the oven-dry weight (tables 3 and 4 and fig. 1). This provides a more understandable concept of the relative amounts of water in a material: specifically, wood or bark having equal amounts of water and dry material have a 100 percent moisture content on an oven-dry basis.

Fuel moisture content is an important factor in determining air requirements and boiler design. Heat losses (heat required to drive off water) are higher for fuels having higher moisture contents. According to Corder (1973), this lowers boiler efficiency.

Seasonal and annual means are reported for most species. In table 4 and figure 1, monthly moisture contents are reported for aspen.

Table 2.--Monthly and seasonal aspen oven-dry weight of wood, oven-dry weight of bark, and moisture weight as a percentage of green weight of wood and bark

Table 2.

Month	Wood	Bark	Moisture	Basis
	Percent	Percent	Percent	No. of loads
June	46.2 (45.2-47.2) ¹	8.9 (8.4-9.4)	44.9 (43.8-46.0)	35
July	47.8 (46.6-49.0)	9.2 (8.6-9.7)	43.0 (42.0-44.1)	32
August	47.8 (46.8-48.9)	9.0 (8.4-9.6)	43.2 (42.1-44.3)	30
Sept.	46.6 (45.3-47.9)	9.5 (8.7-10.4)	43.9 (42.7-45.2)	22
Oct.	43.0 (41.9-44.1)	8.7 (7.6-9.8)	48.3 (46.9-49.6)	13
Summer	46.7 (46.1-47.3)	9.1 (8.8-9.4)	44.2 (43.7-44.8)	132
Nov.	41.2 (39.1-43.2)	8.3 (7.2-9.4)	50.5 (48.8-52.3)	9
Dec.	40.7 (39.9-41.5)	8.6 (8.0-9.3)	50.7 (49.8-51.5)	22
Jan.	40.3 (39.5-41.0)	9.2 (8.5-10.0)	50.5 (49.6-51.4)	25
Feb.	40.8 (40.1-41.5)	8.1 (7.4-8.8)	51.1 (50.1-52.0)	19
March	41.2 (40.5-41.8)	8.3 (7.8-8.8)	50.5 (49.8-51.2)	32
Winter	40.8 (40.4-41.1)	8.6 (8.3-8.9)	50.6 (50.3-51.0)	107

¹ Calculated at a 95 percent confidence interval, which indicates that authors can be 95 percent certain that the values within the parentheses include the true mean.

Table 3.--Mean seasonal and annual moisture content of wood and bark on the oven-dry basis

Table 3.

Species	Period	Basis	Mean Moisture Content		
			Wood	Bark	Wood and Bark
		No. of loads	Percent	Percent	Percent
Black spruce ¹	Winter	82	71.6 (69.2-74.0) ²	81.4 (78.7-84.2)	72.4 (70.1-74.7)
Jack pine	Summer	19	85.2 (76.9-93.5)	75.4 (63.7-87.1)	84.2 (76.1-92.3)
	Winter	13	89.4 (80.1-98.6)	75.1 (64.6-85.6)	88.3 (79.1-97.4)
	Annual	32	86.9 (81.0-92.8)	75.3 (67.5-83.0)	85.9 (80.1-91.6)
Aspen	Summer	132	82.5 (80.4-84.7)	67.5 (66.0-69.0)	80.0 (78.1-81.8)
	Winter	107	111.0 (109.3-112.8)	64.5 (63.1-65.8)	102.9 (101.4-104.5)
	Annual	239	95.3 (93.0-97.6)	66.1 (65.1-67.2)	90.2 (88.3-92.2)
Balsam poplar	Summer	20	129.0 (121.6-136.5)	89.3 (81.5-97.1)	122.3 (116.8-127.9)
	Winter	22	138.8 (132.4-145.2)	81.1 (70.0-92.3)	127.8 (120.7-134.7)
	Annual	42	134.1 (129.2-139.1)	85.0 (78.3-91.8)	125.2 (120.8-129.6)
Balsam fir	Summer	18	154.6 (147.0-162.1)	85.6 (78.9-92.4)	143.9 (136.6-151.2)
	Winter	38	156.8 (150.3-163.4)	89.8 (85.7-94.0)	146.8 (140.9-152.7)
	Annual	56	156.1 (151.2-161.0)	88.5 (85.0-92.0)	145.9 (141.4-150.4)

¹ Black spruce was sampled only during January, February, and March.

² Calculated at a 95% confidence interval, which indicates that authors can be 95% certain that values within parentheses include the true mean.

Table 4.

Month	Moisture Content			Basis
	Wood	Bark	Wood and Bark	
	Percent	Percent	Percent	No. loads
June	84.2 (80.0-88.4) ¹	72.6 (69.1-76.1)	82.2 (78.4-86.0)	35
July	77.9 (73.8-81.9)	67.9 (64.7-71.1)	76.1 (72.7-79.5)	32
August	78.8 (74.7-82.8)	64.9 (62.5-67.3)	76.5 (73.0-80.0)	30
Sept.	82.2 (77.7-86.7)	62.0 (59.5-64.5)	78.7 (74.8-82.6)	22
Oct.	98.8 (93.5-104.1)	67.7 (64.1-71.3)	93.6 (88.6-98.7)	13
Summer	82.5 (80.4-84.7)	67.5 (66.0-69.0)	80.0 (78.1-81.8)	132
Nov.	109.7 (101.8-117.7)	67.2 (64.4-70.0)	102.5 (95.6-109.4)	9
Dec.	111.4 (107.6-115.2)	63.9 (61.3-66.4)	103.0 (99.7-106.3)	22
Jan.	110.6 (106.5-114.7)	66.3 (62.2-70.4)	102.4 (98.8-105.9)	25
Feb.	112.2 (108.1-116.4)	65.9 (62.9-68.9)	104.6 (100.6-108.6)	19
March	110.7 (107.2-114.2)	61.8 (59.9-63.7)	102.5 (99.5-105.4)	32
Winter	111.0 (109.2-112.8)	64.5 (63.1-65.8)	102.9 (101.4-104.5)	107

¹Calculated at a 95 percent confidence interval, which indicates that authors can be 95 percent certain that values within the parentheses include the true mean.

Table 4.--Monthly and seasonal aspen wood and bark moisture contents on an oven-dry basis

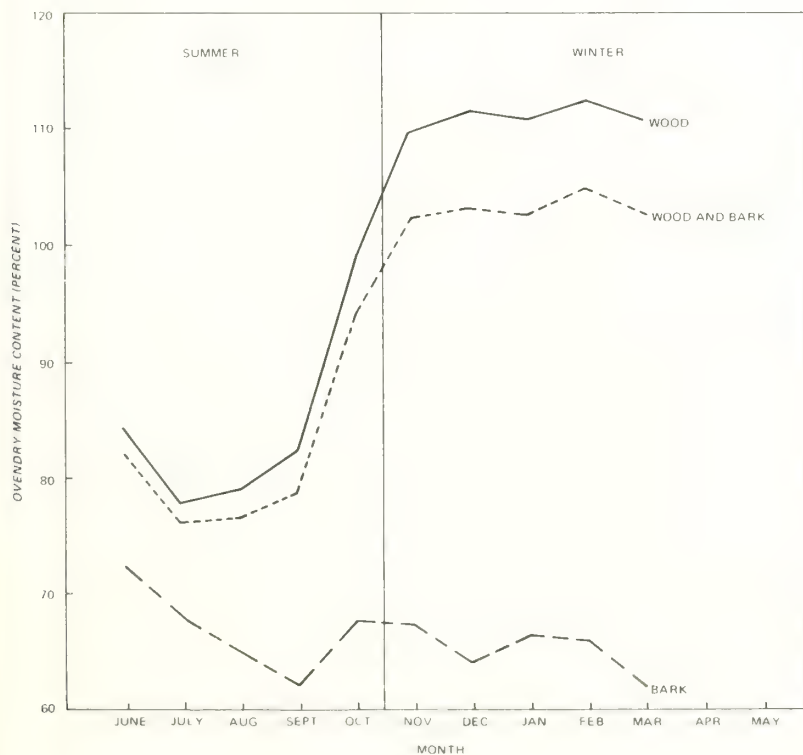


Figure 1.-- Average monthly wood and bark moisture contents (oven-dry basis) for aspen in northern Minnesota.

DOCUMENTATION

Several early studies report on properties of wood and bark for northern pulpwood species: bark thickness and density (Hale 1955); bark volumes and fuel properties (Millikin 1955); moisture content and specific gravity (Yerkes 1967, Erickson 1972); and specific gravity (Lamb and Marden 1968). Weldon (1966) showed it is possible to estimate the amount of bark available for commercial use by applying bark weight data to production statistics. More recently, the prospects and problems of using bark for commercial products and fuel have been summarized in comprehensive reports by the Forest Products Laboratory (Harkin and Rowe 1971); Oregon State University (Van Vliet 1971, Corder 1973); and the University of Canterbury (Ellis 1973).

Study Methods

The data were collected as part of a weight scaling study that involved sampling loads of rough (bark on), 100-inch pulpwood delivered within one week after cutting in northern Minnesota during 1971-1972 (Lothner, Marden, and Kallio 1974). Inasmuch as the moisture content values obtained from this study vary with season, geographical location, time since felling, site, and sampling distribution through the year, the data are only representative of the particular sampling conditions. Likewise, the means and confidence intervals are applicable only to repeated sampling under conditions similar to those used in this study.

We cut a 1-inch disk from the middle of each of three pulp sticks randomly selected from each sample load. The average diameter outside bark (DOB) and average diameter inside bark (DIB) of the disks were measured for determining the bark percentage by volume. The disks were halved, the bark separated from the wood, and each portion weighed to a tenth of a gram.

The bark and wood portions were oven-dried and reweighed. Basic calculations were made (Appendix A) and analyses undertaken to obtain the information presented in tables 1-4.

ANALYSIS

We grouped sample load values by month and season (winter and summer), and calculated group averages and 95 percent confidence intervals accordingly. We used the

one-way analysis of variance or the Kruskal-Wallis test, depending on the homogeneity of variance among groups to test for monthly and seasonal differences among group means.

The sample sizes of jack pine, balsam fir, and balsam poplar were not large enough to report statistically reliable monthly averages. Therefore, only seasonal and yearly averages and confidence intervals were determined.

For black spruce, practically all of the sample loads were obtained during the winter months (January, February, and March). Therefore, we could not analyze any other seasonal differences. In addition, our tests showed there were not any significant differences among the winter months. Therefore, only one average for the January, February, and March period is shown in table 2. The sample load distribution for aspen permitted us to test for monthly differences.

Only yearly averages are shown for percent bark by volume because measurements do not vary through the year. For the stick diameters² sampled, the bark percentage did not vary markedly, but the values for moisture content varied by month and season (tables 2 and 4 and fig. 1).

Moisture Content Differences Within the Pulpwood Stick

To check for moisture content variation within a pulpwood stick, we cut disks within 1 week after felling at the end and middle as well as at 1/2-, 1-, 2-, and 3-foot intervals of each of 33 aspen pulpwood sticks (12 during the summer season and 21 during the winter season). Admittedly this does not constitute a sufficient number of sample sticks to obtain sound statistical evidence, but we can make the following general observations. During the summer season, most drying of the wood takes place within the first foot from the end of the pulpwood stick and the average moisture content falls close to the 1-foot interval. For bark, drying occurs over the entire length of the pulpwood stick. During the winter season, there is not much drying of wood or bark along the stick (fig. 2).

²See Appendix B for stick DOB frequency distributions by species.

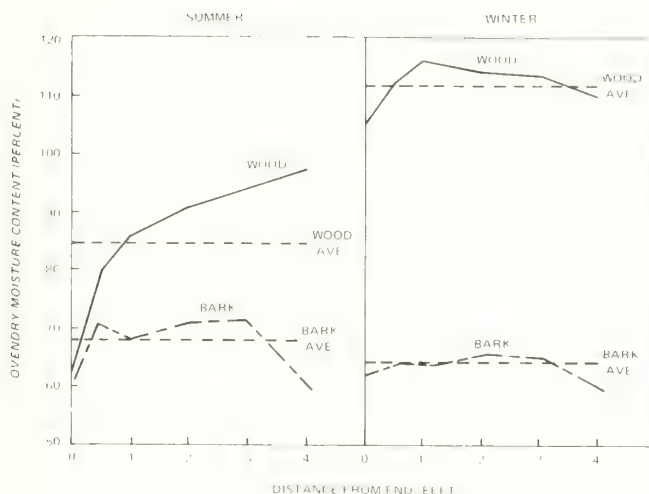


Figure 2.--Aspen wood and bark summer and winter moisture content (ovendry basis) along pulpwood stick.

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APPENDIX A

Basic Calculations

1. The proportion of bark by volume estimate for each load was determined as follows:

$$\text{Proportion bark by volume} = \frac{\sum_{i=1}^{\eta} \text{DOB}^2 - \sum_{i=1}^{\eta} \text{DIB}^2}{\sum_{i=1}^{\eta} \text{DOB}^2}$$

where η = number of disks cut from each load, 1-3.

2. The estimate of percent moisture content of bark and wood on an oven-dry basis for each load was determined by:

$$\text{Percent moisture content} = \left[\frac{\sum_{i=1}^{\eta} \text{green wt.} - \sum_{i=1}^{\eta} \text{oven-dry wt.}}{\sum_{i=1}^{\eta} \text{oven-dry wt.}} \right] \times 100$$

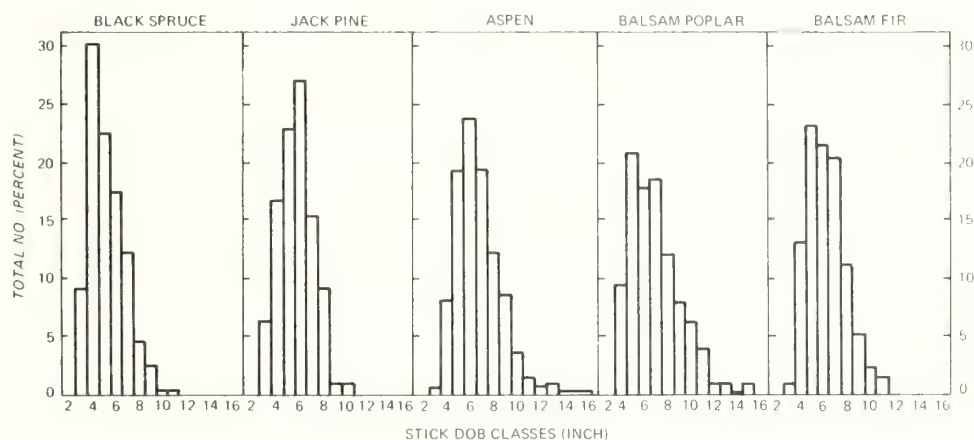
3. The percent of the total green weight represented by bark, wood, and moisture was determined as follows:

$$\text{a. Percent oven-dry wt. wood (or bark)} = \frac{\sum_{i=1}^{\eta} \text{OD wt. wood (or bark)}}{\sum_{i=1}^{\eta} \text{green wt. of wood (or bark)}} \times 100$$

$$\text{b. Percent Moisture} = \frac{\sum_{i=1}^{\eta} \text{green wt. wood and bark} - \sum_{i=1}^{\eta} \text{OD wt. wood and bark}}{\sum_{i=1}^{\eta} \text{green wt. of wood and bark}}$$

APPENDIX B

Stick DOB Frequency Distribution by Species



Marden, Richard M., David C. Lothner, and Edwin Kallio.

1975. Wood and bark percentages and moisture contents of Minnesota pulpwood species. USDA For. Serv. Res. Pap. NC-114, 9 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

To help increase the use of bark for fuel or products, information is presented on the relative proportions of bark and wood by volume and weight, and also moisture contents (ovendry basis) for five northern Minnesota pulpwood species.

OXFORD: 861.0:523.0:812.211(776). KEY WORDS: weight scaling, Jack pine (*Pinus banksiana* Lamb.), Black spruce (*Picea mariana* (Mill.) B.S.P.), Balsam fir (*Abies balsamea* (L.) Mill.), Quaking aspen (*Populus tremuloides* Michx.), Balsam poplar (*Populus balsamifera* L.)

Marden, Richard M., David C. Lothner, and Edwin Kallio.

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Debarking ships from whole trees in the lake states

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CONTENTS

Objectives	2
Sample Material.	2
Test Procedure	5
Results.	5
Conclusions.	8

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DEBARKING CHIPS FROM WHOLE TREES IN THE LAKE STATES

James A. Mattson

Field chipping of whole trees, coupled with an effective system for removing the bark from the chip mass, is a means of increasing the utilization of our forest resources.¹ By chipping in the field, the tops and limbs currently left in the forest can be recovered, and stands that are marginal or submarginal with present harvesting systems can possibly be harvested economically. A system that could effectively remove the bark from the chip mass would make whole-tree chips suitable for most paper-making processes and ensure an adequate market.

Several years of research at the Forest Engineering Laboratory (FEL) has shown that a process that will remove the bark from a chip mass is technically feasible.² The part of the bark-chip separation-segregation (BCSS) system developed at the FEL is a compression debarker (fig. 1) that basically consists of two compression rolls that are hydraulically loaded to maintain a small "nip" spacing as chips pass between the rolls. Pressure separates the bark from the wood. The wood chips pass straight through the nip while the bark adheres to the rolls and is collected separately. Compression debarking alone can remove 50 to 70 percent of the bark in a chip mass.

¹ John R. Erickson. *Bark-chip segregation: a key to whole-tree utilization*. For. Prod. J. 21(9):111-113. 1971.

² Rodger A. Arola and John R. Erickson. *Compression debarking of wood chips*. USDA For. Serv. Res. Pap. NC-85, 4 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn. 1973.

Steaming the chips before compression removes significantly more bark. Steaming apparently softens the cambial layer of the bark and makes the bark tacky so that it adheres better to the compression-debarker rolls. Steaming before compression can increase total bark removal as much as an additional 30 percent of input bark.

The bark left in the chip mass after presteaming and compression debarking is concentrated in the small size fractions of the output. Earlier work has shown that mechanical attrition is feasible for reducing residual bark even further.³ To obtain a final output that is practically bark free, a combination of presteaming, compression debarking, attrition, and removal of the smallest material (both bark and wood) from the output should be used. (The FEL has used 3 percent or less residual bark as the objective of the bark removal research, as recommended by the American Pulpwood Association.)

Mostly bolewood has been used in developing the BCSS system. This choice was made to reduce the number of variables in the test program and to simplify material acquisition and handling. However, before the BCSS system could be considered a solution to the problem of bark removal after chipping, it had to be demonstrated that BCSS could achieve acceptable results with whole-tree chips in all seasons of the year.

³ James A. Mattson. *Beneficiation of compression debarked wood chips*. USDA For. Serv. Res. Note NC-180, 4 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn. 1974.

SR-SMOOTH STEEL ROLL
KR-KNURLED STEEL ROLL

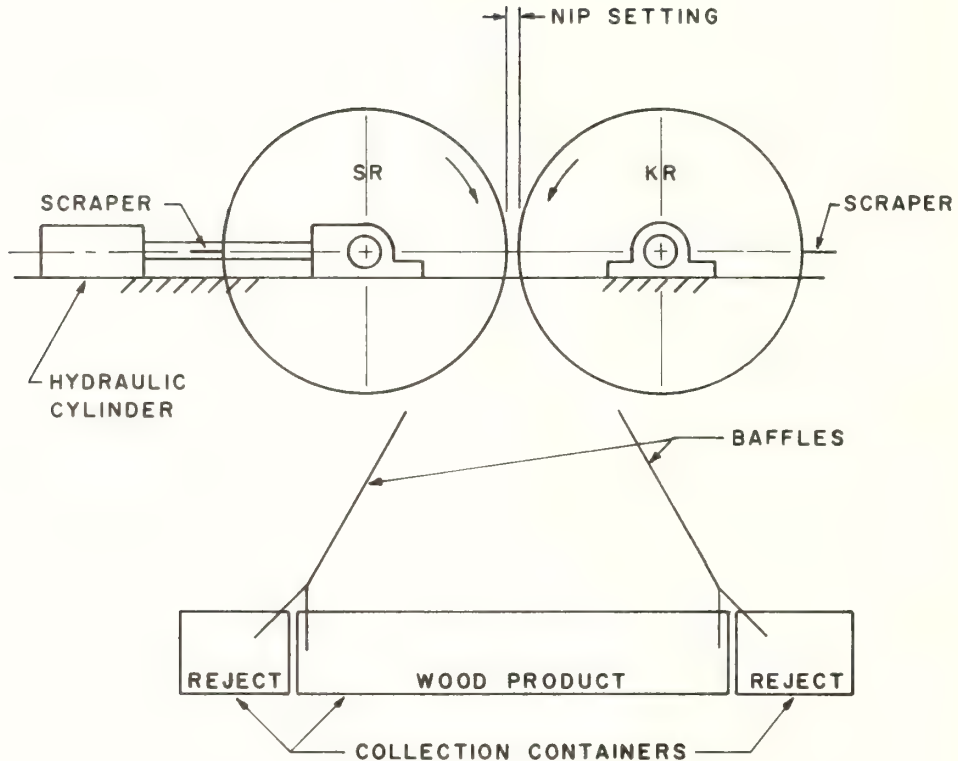


Figure 1.--Simplified schematic diagram of the compression debarker.

OBJECTIVES

The objective of this study was to evaluate, in terms of bark removal and wood recovery, the effectiveness of the compression debarker plus the complementary pre-steaming and attrition treatments on whole-tree chips of three major Lake States species, quaking aspen (*Populus tremuloides* Michx), sugar maple (*Acer saccharum* Marsh), and jack pine (*Pinus banksiana* Lamb).

SAMPLE MATERIAL

Three sample trees of each species were cut bimonthly from March 1973 to January 1974.

All the trees were obtained from the lands of the Ford Forestry Center of Michigan Technological University near L'Anse, Michigan. The trees were chipped with a Morbark Chip-pac⁴ owned and operated by the Ford Forestry Center. The chipper was equipped with an oversize screen and has rechipping capability so oversized chips were eliminated. The chipper has a 9-inch spout so the trees sampled in this study were all in the 6-to 8-inch diameter class (table 1).

⁴ Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.

Table 1.--Data on trees chipped¹

ASPEN								
Date	D.b.h.	Height	Age	Total green weight	Moisture content ²	Specific gravity ³		
cut and chipped				of chips	Wood	Bark	Wood	Bark
	Inches	Feet	Years	Lbs	Percent	Percent		
3-13-73	7.0	66.3	75.0	464	100.9	77.2	0.376	0.539
5-16-73	6.9	67.1	73.7	497	106.1	77.0	.378	.544
8-3-73	7.0	68.6	74.0	522	98.5	100.4	.366	.472
9-26-73	6.9	64.0	76.7	456	88.4	97.5	.374	.499
11-28-73	7.0	68.7	69.7	533	103.5	86.9	.368	.526
1-18-74	7.2	67.6	70.3	608	121.4	89.8	.349	.500
Mean	7.0	67.0	73.2	513	103.1	88.1	.368	.513
SUGAR MAPLE								
3-22-73	6.9	49.6	71.3	495	63.6	55.3	0.601	0.605
5-23-73	6.8	50.9	61.0	419	58.6	67.2	.598	.536
7-23-73	6.9	52.0	74.3	432	58.3	89.1	.545	.459
9-27-73	6.6	57.4	71.7	445	56.4	81.6	.581	.468
11-20-73	7.0	58.4	71.0	519	64.8	64.4	.584	.512
1-23-74	6.8	56.1	65.0	463	69.4	55.4	.558	.566
Mean	6.8	54.1	69.1	462	61.9	68.8	.578	.524
JACK PINE								
3-23-73	7.1	53.0	42.3	449	103.5	158.2	0.368	0.295
5-9-73	6.8	50.5	40.7	425	121.1	150.0	.367	.314
7-11-73	7.2	54.5	43.3	456	127.9	207.0	.350	.256
9-14-73	6.9	53.6	45.0	447	108.4	208.9	.361	.285
11-29-73	6.9	54.1	45.7	449	103.2	167.2	.374	.338
1-25-74	7.6	51.8	44.0	508	100.6	163.5	.361	.294
Mean	7.1	52.9	43.5	456	110.8	175.8	.363	.297

¹Mean values for three trees.²Oven-dry.³Dry weight/green volume.

After chipping, the material from each tree was thoroughly mixed and a 100-pound sample taken for analysis. The 100-pound sample was screened into several size classes (1/8 inch, 5/8 inch, 3/8 inch, 3/16 inch, and fines), and smaller samples were taken from each size class to obtain bark and foliage contents. Additional samples were taken to determine moisture contents and specific gravities of the wood and bark.

The season in which the trees are cut has a significant effect on the amount of bark-wood (wood chips with bark still attached) present in the chips. The bark-wood in the sample chips ranged from 2 to 10 percent of the total chip mass depend-

ing on the season (table 2). The added requirements of breaking the bark-wood bond before segregating the bark from the wood reduces the amount of bark that can be removed by one pass through the compression debarker.

Most chips are in the 5/8-inch and 3/8-inch size fraction (table 3). These two size fractions contain over 70 percent of the total material and about 80 percent of the total wood present in the chip mass. The smaller chips contain a greater proportion of the bark than the larger chips, but the bark percents in all size fractions is too high to selective screen chips to obtain a product with an acceptable level of bark.

Table 2.--Chip analysis of whole-tree
chips by cutting date¹
(In percent)

ASPEN									
Cutting date	Free : wood	Free : bark	Bark- : wood	Wood : Wood	Bark : Bark	Total : wood	Total : bark	Twigs	Foliage
3-73	65.27	13.84	20.30	50.08	41.92	77.07	22.34	0.59	0
5-73	72.58	20.42	5.92	54.72	45.28	75.88	23.03	1.08	0
7-73	71.73	18.72	6.99	61.94	38.06	76.04	21.42	1.11	1.44
9-73	66.23	16.17	15.08	59.24	40.76	75.23	22.26	1.27	1.25
11-73	69.95	15.08	14.29	57.26	42.74	78.11	21.21	.68	0
1-74	73.69	17.98	7.91	53.10	46.90	77.90	21.68	.43	0
SUGAR MAPLE									
3-73	77.95	11.39	9.05	82.90	17.08	85.45	12.93	1.62	0
5-73	81.42	13.98	2.90	79.35	20.65	83.73	14.57	1.69	0
7-73	78.77	13.36	2.14	79.21	20.79	80.46	13.81	1.96	3.78
9-73	72.28	11.53	11.52	80.66	19.34	81.62	13.72	2.65	2.02
11-73	77.26	10.42	10.54	79.48	20.52	85.63	12.59	1.78	0
1-74	77.58	11.35	9.48	82.80	17.20	85.43	12.96	1.61	0
JACK PINE									
3-73	68.88	5.95	18.12	82.27	17.73	83.73	9.19	2.06	4.98
5-73	72.13	11.06	4.92	76.89	23.11	75.93	12.18	3.97	7.93
7-73	75.62	11.57	3.88	80.14	19.86	78.83	12.34	2.94	5.99
9-73	69.08	8.73	12.09	83.67	16.33	79.21	10.69	3.32	6.77
11-73	67.38	6.96	16.02	79.72	20.28	80.16	10.20	3.23	6.41
1-74	77.15	7.09	9.47	74.71	25.29	84.23	9.49	2.33	3.95

¹Mean values for three trees.

Table 3.--Chip analysis of whole-tree
chips by size fractions¹
(In percent)

Chip size (inches)	Total : chips	Wood	Bark	Twigs	Foliage	Total : wood in run	Total : bark in run
1-1/8	9.41	81.50	15.64	2.16	0.70	10.10	6.38
5/8	55.23	87.22	11.71	.72	.35	62.81	29.41
3/8	25.33	65.05	33.77	.85	.33	21.58	38.49
3/16	6.98	45.90	52.56	.81	.73	4.23	16.51
Fines	3.05	31.23	67.22	0	1.54	1.28	9.21
Total	100	76.70	21.99	.86	.45	100	100
SUGAR MAPLE							
1-1/8	17.22	93.20	2.80	3.45	0.56	19.33	3.52
5/8	51.77	93.10	4.88	1.23	.79	57.56	18.67
3/8	21.21	73.65	23.17	2.20	.98	18.80	35.56
3/16	6.86	42.38	51.37	3.67	2.58	3.50	26.20
Fines	2.93	21.64	74.24	.05	4.07	.81	16.05
Total	100	83.72	13.43	1.89	.97	100	100
JACK PINE							
1-1/8	10.82	86.06	5.26	4.77	3.91	11.72	5.41
5/8	48.29	89.29	5.39	1.55	3.81	53.62	24.28
3/8	25.37	83.93	10.03	3.92	2.12	26.55	23.36
3/16	10.12	53.25	22.71	7.84	16.20	6.79	21.68
Fines	5.40	18.34	51.15	0	30.51	1.31	25.27
Total	100	80.36	10.68	2.97	6.01	100	100

¹Mean values for 18 trees.

TEST PROCEDURE

Four 50-pound batches of chips were taken from each tree. Each batch was processed for bark removal by a different treatment as follows:

1. Compression debarked only (hereafter referred to as process "C"). (For all compression debarker runs, the machine variables were set at previously determined optimum values: 0.020-inch nip spacing, 1,400 pounds/lineal inch hydraulic pressure on the rolls, 640 surface feet/minute roll speed, and 1 ft³/minute feed rate.)
2. Presteamed at 10 lb/in.² for 5 minutes and compression debarked. (Process "S10C".)
3. Presteamed at 30 lb/in.² for 5 minutes and compression debarked. (Process "S30C".)
4. Process S30C followed by a hammer-milling of the two smaller size fractions of the compression debarker output (those chips that passed a 5/8-inch screen but were retained on a 3/16-inch screen). The hammer-mill used in this study was a modified laboratory coal crusher equipped with a bar screen with the bars running perpendicular to the axis of the hammer shaft (fig. 2). Three solid full-length hammers were used in the mill. (The hammermill was used on the last four cuttings only.)

Each run was analyzed for size classes, percent of wood, bark, and foliage by size classes, percent of input bark and foliage removed, and percent of input wood recovered. Analysis was done on an oven-dry basis.

RESULTS

The tests show that bark removal for process S30C is significantly better than for process S10C and process C for all tree species during all cutting seasons (fig. 3). Process S30C removes an average of 12.5 percent more bark than process S10C and an average of 33.3 percent more bark than process C.

Wood recovery for aspen is not significantly different for the three processes or cutting seasons, but both aspen and jack pine wood recovery are affected by both process and cutting season. Wood recovery for jack pine and maple is

significantly lower for process S30C than for the other processes; maple wood recovery is lower during the foliage season and jack pine wood recovery is significantly lower during the dormant season. A significant portion of the wood lost during steaming and compression debarking adheres to the knurled roll of the compression debarker. The use of the two smooth rolls on the compression debarker is being investigated as one means of reducing this loss. A separate study has also indicated that about 70 percent of the wood fiber that is removed by the knurled roll can be easily recovered.⁵

The presteaming-compression debarking process is effective in removing foliage from whole-tree chips of jack pine only; an average of 58 percent of the input foliage. Similar to the residual bark, the residual foliage is concentrated in the small size fractions of the output from the compression debarker.

The total mean residual bark content of the presteamed and compression debarked chips (process S30C) ranges from 3.36 percent to 5.30 percent for aspen, 4.22 percent to 7.35 percent for maple, and 3.19 percent to 4.54 percent for jack pine (table 4). Thus, the presteaming and compression debarking process alone does not reduce the residual bark content to the desired level of 3 percent or less. For all species and cutting seasons, the residual bark content of the 1-1/8-inch and 5/8-inch size classes are less than 3 percent, but both the 3/8-inch and 3/16-inch size classes exceed the desired bark content for all species because the bark is concentrated in these fractions (table 5).

Hammermilling the chips smaller than 5/8-inch from the compression debarker output further reduces the size of the bark particles and concentrates the residual bark in the 3/16-inch size fraction. Removal of this size fraction then reduces the output to less than 3 percent bark for all conditions (table 6). The addition of the hammermilling and eliminating the 3/16-inch size fraction also reduces the wood recovery to a range of 71 to 88 percent. However, the particles removed are of uniform size and should be ideally suited for use either in particleboard or as boiler fuel.

⁵ Rodger A. Arola. *Fiber recovery from compression debarking roll waste. (In process.)*

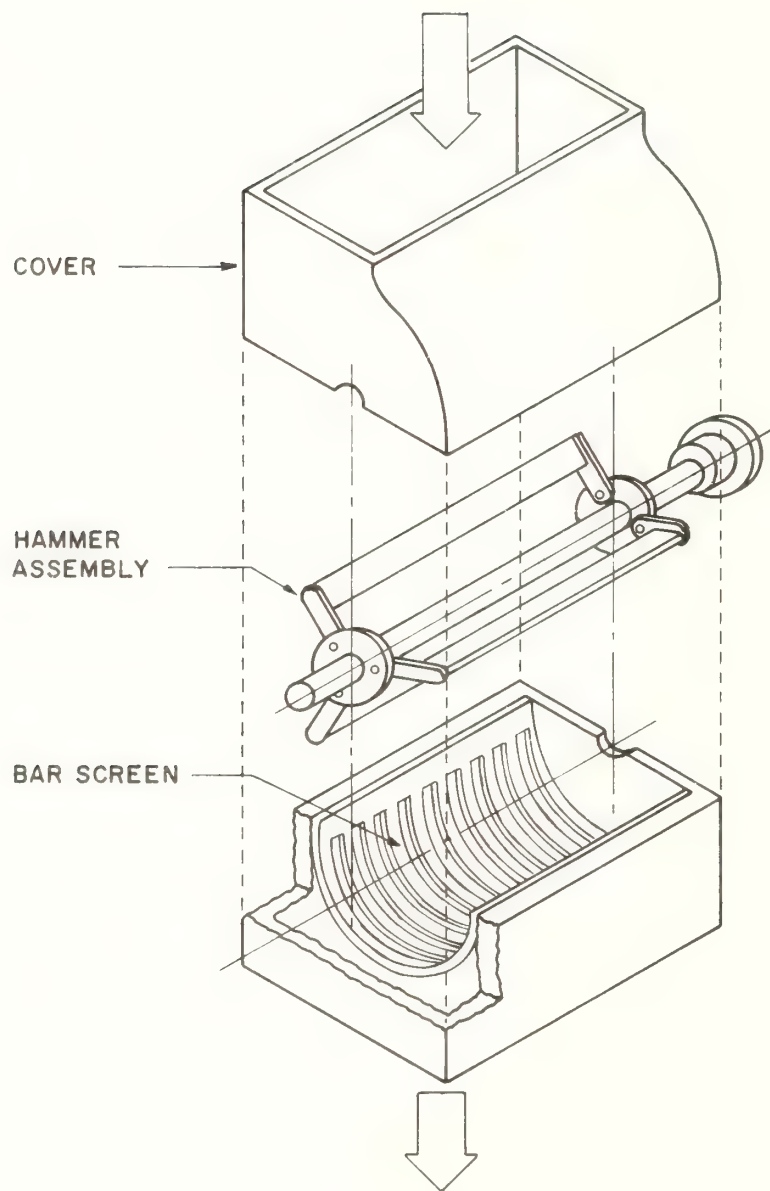


Figure 2.--Schematic of hammermill used to beneficiate output of compression debarker.

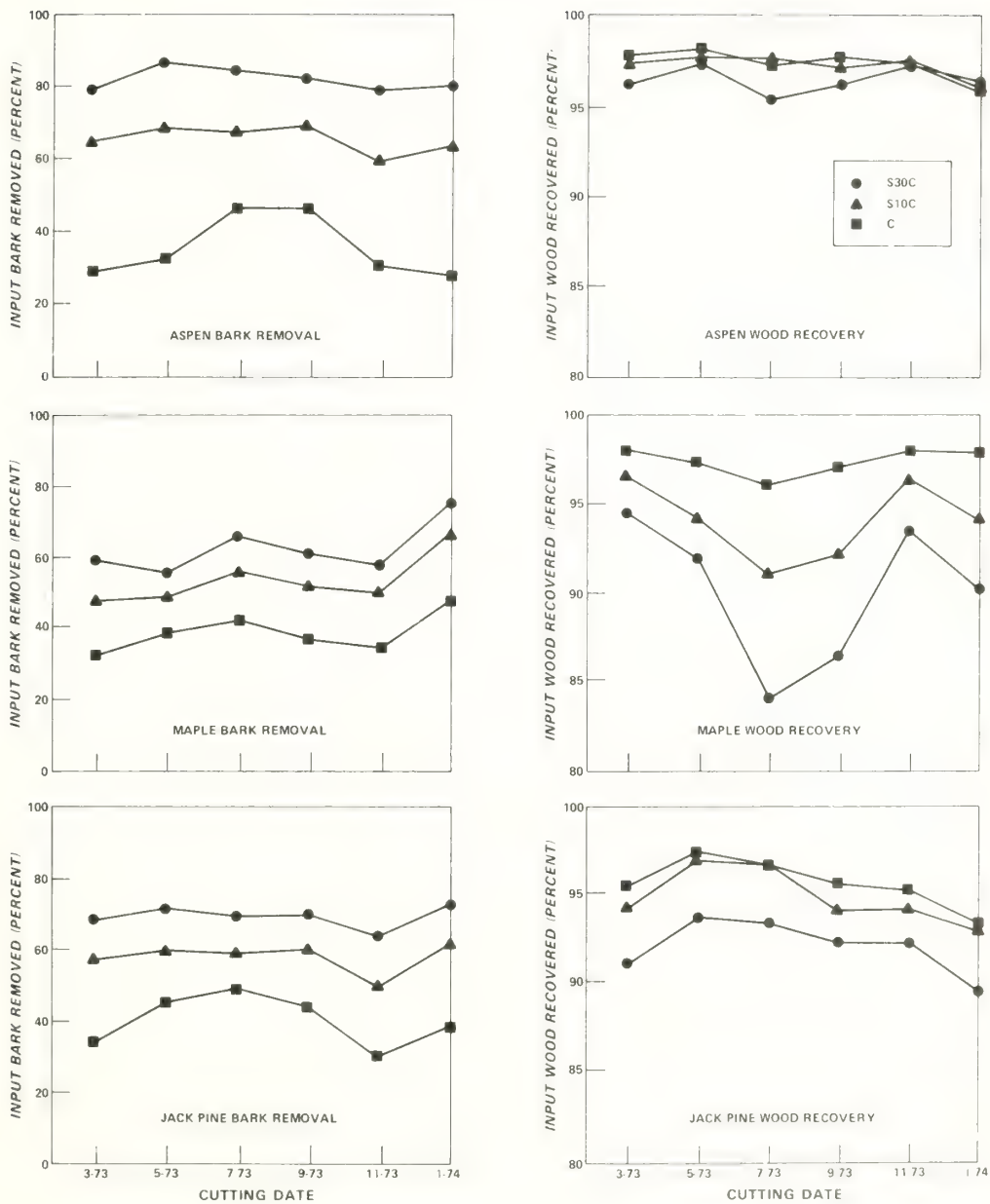


Figure 3.--Bark removal and wood recovery for aspen, sugar maple, and jack pine for processes S30C, S10C, and C by cutting date.

Table 4.--*Compression debarking¹ results
for whole-tree chips
(In percent)*

ASPEN									
Cutting date	Input bark	Output bark	Input bark removed	Input Foliage	Output Foliage	Input foliage removed	Total weight removed	Input wood recovered	
3-73	19.34 ² (0.67)	4.82 (0.25)	79.67 (0.54)	--	--	--	18.44 (0.94)	96.24 (0.81)	
5-73	21.18 (1.38)	3.36 (0.54)	87.43 (1.12)	--	--	--	20.53 (0.91)	97.43 (0.25)	
7-73	20.14 (0.79)	3.97 (0.24)	84.38 (0.20)	0.96 (0.31)	0.86 (0.28)	28.11 (6.10)	20.82 (1.17)	95.48 (0.66)	
9-73	21.42 (0.73)	4.75 (0.45)	82.34 (2.40)	1.05 (0.37)	1.05 (0.42)	21.32 (3.75)	20.75 (0.96)	96.27 (0.15)	
11-73	19.98 (0.36)	4.93 (1.20)	79.72 (5.51)	--	--	--	18.13 (1.73)	97.33 (0.61)	
1-74	21.54 (0.38)	5.30 (0.92)	80.35 (3.43)	--	--	--	20.22 (1.10)	96.29 (0.93)	
SUGAR MAPLE									
3-73	12.81 ² (1.01)	5.87 (0.82)	59.90 (3.83)	--	--	--	12.37 (2.35)	94.62 (3.11)	
5-73	14.24 (0.14)	7.35 (0.34)	56.09 (2.86)	--	--	--	14.86 (3.65)	91.99 (3.85)	
7-73	14.33 (1.27)	6.45 (2.06)	66.10 (6.89)	1.85 (0.58)	1.58 (0.69)	31.92 (10.45)	23.15 (4.31)	83.93 (5.29)	
9-73	14.25 (1.51)	6.90 (0.79)	61.56 (2.56)	1.79 (0.84)	2.03 (1.04)	18.72 (4.27)	20.65 (3.22)	86.50 (3.69)	
11-73	14.01 (0.70)	6.80 (1.19)	58.16 (6.45)	--	--	--	13.64 (2.54)	93.59 (2.26)	
1-74	14.10 (0.43)	4.22 (0.21)	75.80 (0.93)	--	--	--	19.10 (3.40)	90.22 (4.40)	
JACK PINE									
3-73	8.63 ² (0.76)	3.19 (0.20)	68.69 (1.80)	3.34 (0.95)	1.80 (0.48)	54.24 (2.56)	15.58 (1.70)	91.11 (1.10)	
5-73	12.48 (0.76)	4.30 (0.50)	71.47 (1.60)	4.84 (0.38)	2.48 (0.56)	57.73 (7.07)	16.91 (0.56)	93.69 (0.56)	
7-73	10.33 (0.62)	3.74 (0.37)	69.34 (0.94)	3.53 (0.57)	1.44 (0.23)	65.12 (2.64)	15.12 (2.56)	93.42 (2.41)	
9-73	11.24 (1.17)	4.06 (0.30)	69.76 (2.45)	3.99 (0.64)	2.14 (0.32)	55.29 (4.47)	16.63 (1.72)	92.26 (1.36)	
11-73	10.29 (1.37)	4.54 (0.29)	62.66 (3.45)	4.82 (0.75)	2.36 (0.44)	59.09 (1.75)	16.60 (0.48)	92.13 (0.88)	
1-74	9.99 (1.12)	3.52 (0.83)	71.44 (3.53)	3.07 (0.91)	1.56 (0.49)	58.70 (2.18)	18.05 (0.53)	89.49 (0.53)	

¹Process S30C.

²Mean with standard deviation in parenthesis.

CONCLUSIONS

Presteam followed by compression debarking can remove 55 to 90 percent of the input bark in a mass of whole-tree chips of three major Lake States species, quaking aspen, sugar maple, and jack pine. Residual bark contents range from 3.2 percent to 7.5 percent and wood recovery from 80 to 97 percent.

Addition of a hammermill treatment on the size fraction smaller than 5/8-inch after compression debarking and elimination of the bark-heavy 3/16-inch size fraction

reduces the residual bark content to 3 percent or less for all three species. Thus, whole-tree chips processed by the BCSS system of the Forest Engineering Laboratory are suitable for use in all but the most stringent pulping operations.

It is true that more wood is lost in BCSS than in conventional roundwood debarking systems. However, the increased amount of fiber recovered per acre when whole-trees are harvested will mean more clean chips available for pulping. In addition, the reject material from the BCSS can easily be used in a secondary product or as fuel.

Table 5.--Output, bark, and foliage
remaining in chips of various sizes
after presteam and compression
debarking whole-tree chips
(In percent)

ASPEN													
Cutting :		1-1/8 inch :			5/8 inch :			3/8 inch :			3/16 inch :		
date	Output	Bark	Foliage	Output	Bark	Foliage	Output	Bark	Foliage	Output	Bark	Foliage	
3-73	7.55	0.54	0	61.82	0.71	0	24.09	7.67	0	6.54	38.35	0	
5-73	6.80	.38	0	63.18	.21	0	23.87	5.58	0	6.15	30.39	0	
7-73	9.96	.11	1.18	63.40	.85	0.72	20.93	7.38	0.63	5.71	33.37	2.93	
9-73	8.33	.48	1.18	62.35	.93	.70	22.46	7.19	1.56	6.86	37.13	2.47	
11-73	5.33	.26	0	60.55	.82	0	27.25	7.62	0	6.88	33.54	0	
1-74	4.72	.39	0	59.37	.93	0	27.85	8.21	0	8.06	30.15	0	
SUGAR MAPLE													
3-73	9.89	0.41	0	58.61	0.62	0	23.18	6.76	0	8.33	47.09	0	
5-73	13.45	.50	0	56.22	.96	0	22.41	12.85	0	7.92	48.52	0	
7-73	12.48	.47	0.50	59.24	1.55	1.43	20.97	12.10	3.35	7.30	39.96	6.28	
9-73	17.42	.94	.53	50.82	1.03	1.12	22.60	10.97	1.93	9.15	40.82	5.27	
11-73	12.25	.59	0	55.83	.94	0	23.61	10.09	0	8.30	46.02	0	
1-74	8.43	.72	0	55.23	.57	0	27.38	4.29	0	8.96	33.10	0	
JACK PINE													
3-73	6.04	0.67	0.09	49.89	0.45	0.20	34.26	3.21	1.06	9.81	18.87	13.49	
5-73	6.02	1.09	0	50.55	.71	0	32.68	4.29	0.95	10.75	23.09	20.16	
7-73	7.55	.62	.05	50.83	.84	0	31.72	4.42	.48	9.90	19.11	13.23	
9-73	6.17	.80	.12	50.94	.58	0	31.89	4.31	.71	10.99	21.34	17.40	
11-73	4.88	1.01	.16	52.85	1.17	.10	31.40	5.66	.95	10.87	19.42	18.33	
1-74	3.23	1.19	.13	44.58	.78	0	37.95	2.61	.92	14.24	14.84	8.35	

¹Process S30C.

Table 6.--Compression debarking results
with minus 5/8-inch fraction hammer-
milled and minus 3/8-inch fraction
discarded from output
(In percent)

ASPEN								
Cutting : date	Input : bark	Output : bark	Input : bark removed	Input : Foliage	Output : Foliage	Input : foliage removed	Total : weight removed	Input wood recovered
7-73	19.03 ² (0.79)	1.26 (0.22)	95.26 (0.94)	1.12 (0.12)	0.89 (0.20)	43.92 (8.46)	28.38 (0.69)	87.78 (0.52)
9-73	21.59 (1.02)	1.65 (0.06)	94.67 (0.55)	1.09 (0.19)	0.95 (0.12)	38.77 (9.79)	30.33 (1.92)	87.76 (1.90)
11-73	20.14 (0.19)	1.79 (0.31)	93.60 (1.15)	--	--	--	28.17 (0.34)	88.35 (0.38)
1-74	21.42 (0.88)	1.71 (0.83)	94.41 (2.79)	--	--	--	30.58 (1.44)	86.83 (1.95)
SUGAR MAPLE								
7-73	14.17 (0.50)	1.99 (0.77)	90.68 (3.43)	1.87 (0.96)	1.49 (0.84)	47.06 (7.92)	33.39 (1.16)	76.57 (1.40)
9-73	15.02 (1.05)	2.34 (0.55)	89.52 (3.45)	1.44 (0.51)	0.97 (0.63)	59.06 (11.41)	33.70 (3.75)	76.73 (3.86)
11-73	13.56 (1.09)	1.60 (1.23)	91.32 (6.28)	--	--	--	24.95 (2.55)	85.45 (3.03)
1-74	14.15 (1.05)	1.16 (0.21)	94.43 (0.40)	--	--	--	31.32 (3.67)	79.07 (3.81)
JACK PINE								
7-73	10.27 (0.56)	1.40 (0.52)	90.45 (3.14)	3.75 (0.39)	0.22 (0.08)	95.84 (1.57)	28.99 (2.04)	81.27 (2.75)
9-73	10.76 (1.09)	1.03 (0.48)	93.66 (2.53)	3.95 (0.68)	0.21 (0.09)	96.29 (1.61)	32.43 (2.50)	78.28 (3.58)
11-73	10.79 (0.88)	2.12 (0.10)	86.53 (1.60)	4.74 (0.11)	0.51 (0.22)	92.53 (3.55)	31.75 (3.16)	78.66 (3.20)
1-74	11.65 (3.30)	1.83 (0.49)	89.01 (5.79)	3.77 (1.30)	0.34 (0.19)	94.75 (1.21)	38.52 (7.56)	70.92 (5.01)

¹Process S30C.

²Mean with standard deviation in parenthesis.

Mattson, James A.

1975. Debarking chips from whole trees in the Lake States.

USDA For. Serv. Res. Pap. NC-115, 9 p., illus. North
Cent. For. Exp. Stn., St. Paul, Minn.

Presents the results of a one-year study to evaluate the efficiency of the bark-chip separation-segregation system on whole-tree chips of quaking aspen, sugar maple, and jack pine. A residual bark content of 3 percent or less was achieved with all three species during all cutting seasons.

OXFORD: 821:825.71(77). KEY WORDS: Quaking aspen, bark, beneficiation, jack pine, pulpwood, sugar maple.

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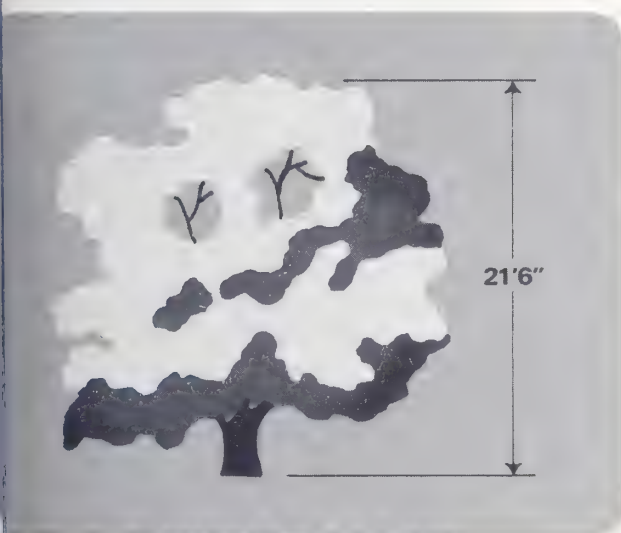
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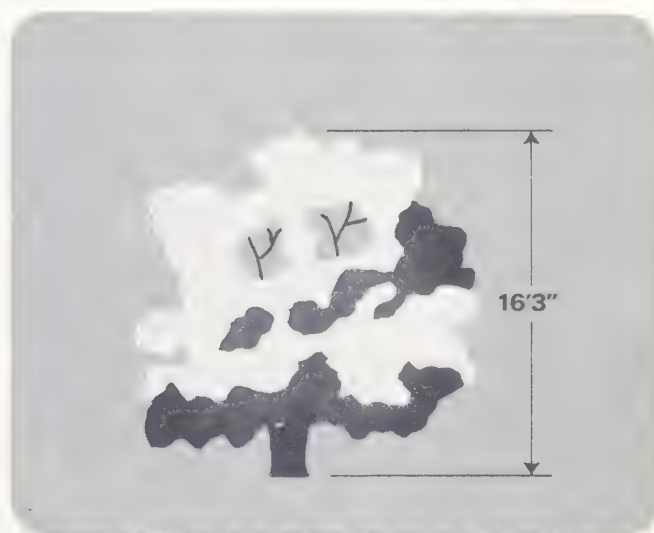
Growth of four types of white oak reproduction after clearcutting in the Missouri Ozarks



ROBERT A.
McQUILKIN

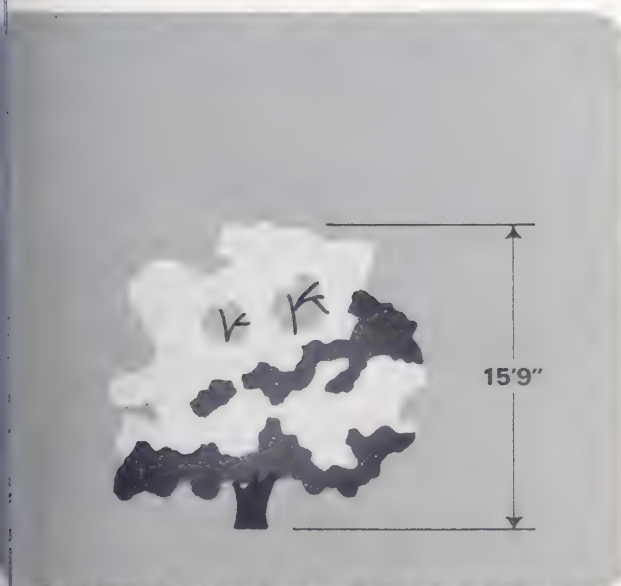


STUMP SPROUT



CUT SEEDLING SPROUT

10 YEARS OF GROWTH



UNCUT SEEDLING SPROUT



SEEDLING

ROBERT A. MC QUILKIN is an Associate Silviculturist
for the Station. He is located at the Station's field
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1975

CONTENTS

Methods	1
Seedlings.	1
Seedling Sprouts	1
New Seedling Sprouts	1
Stump Sprouts.	1
Results	2
Discussion and Summary.	4
Example.	4
Literature Cited.	5



GROWTH OF FOUR TYPES OF WHITE OAK REPRODUCTION AFTER CLEARCUTTING IN THE MISSOURI OZARKS

Robert A. McQuilkin

Regeneration of oak stands after clear-cutting depends on advance reproduction (seedlings and seedling sprouts present at the time of the cutting) and stump sprouts (Sander and Clark 1971). The study reported here corroborates that fact, and presents data on the survival and height growth of four types of white oak (*Quercus alba* L.) reproduction following clearcutting in even-aged white oak stands in the Missouri Ozarks.

METHODS

Sixteen 0.1-acre plots were established in even-aged oak stands on the Sinkin Experimental Forest in southeastern Missouri. The stands were composed primarily of white oak; black oak (*Q. velutina* Lam.) and scarlet oak (*Q. coccinea* Muenchh.) were minor stand components. Stand ages were between 41 and 58 years, and site indexes (McQuilkin 1974) ranged from 48 to 63 feet.

The plots were clearcut in April 1963. After the cutting, four types of white oak reproduction were established in a completely randomized design on the 16 plots; one reproduction type was established per plot, and each type was established on four randomly selected plots. Twenty-five individual plants were established or located on each plot to give a total of 100 plants of each reproduction type over the entire study.

The four types of reproduction were seedlings, seedling sprouts, new seedling sprouts, and stump sprouts.

Seedlings

Seedlings are young plants with tops and roots of the same age. In this study,

seedlings were obtained by direct seeding after the clearcut and planting 1-0 nursery stock (from the same seed source) where the direct seeding failed to produce the necessary 25 seedlings per plot. On the 4 seedling plots, 48 direct-seeded seedlings were alive at the end of the first growing season, and 52 1-0 seedlings were planted as replacements.

Seedling sprouts

Sprouts with root systems several-to-many years older than the tops are seedling sprouts. These develop as a result of repeated top dieback and resprouting (Merz and Boyce 1956). To ensure that the roots were at least several years older than the tops, seedling sprouts were selected that had a root at least 1 inch in diameter at the ground line but had a top less than 0.5-inch d.b.h. The mean height of the 100 selected stems was 2.2 feet.

New seedling sprouts

New sprouts originating from the base of seedling sprouts (described above) are new seedling sprouts. In this study, these were created by cutting off the tops of seedling sprouts just above the root collar.

Stump sprouts

Sprouts originating from stumps of the overstory trees are stump sprouts. They were selected 4 months after the trees were cut, and only those stumps that had already produced at least one sprout were selected. One plot had only 24 sprouting stumps, so the stump sprout data for the whole study are based on a total of 99 stumps.

Immediately after the clearcut, understory stems down to 0.5-inch d.b.h. were cut on the seedling sprout plots, and all

understory vegetation (other than the study trees) was cut on the rest of the plots.

All study plants were released from competing vegetation after the first and second growing seasons. No further release was done after that.

The survival, height, and form of all study trees were measured each fall for 10 years. If more than one stem per plant was present, the height of the tallest stem was measured. Form was recorded as: *good*--single, straight, erect stem; *fair*--leaning stem or multiple stems of unequal height; or *poor*--multiple stems of about equal height, flat-topped crowns, excessive sweep or crook, or trees with stem decay.

RESULTS

Survival of the four reproduction types after 10 years was:

	Percent
Seedlings	79
Seedling sprouts	95
New seedling sprouts	93
Stump sprouts	97

As expected the stump sprouts grew the most; height growth of the seedling sprouts and the new seedling sprouts (which differed very little from each other) was about 75 percent of that of the stump sprouts; seedling growth was only 12 percent of that of the stump sprouts (fig. 1).

Often the range and distribution of heights can be more informative than just mean heights, so the data are presented in figure 2 as the percents of the total number of originally selected stems that attained various minimum heights after 10 years.¹ Mortality is represented by the difference on the vertical axis between the data line intercept and 100 percent.

Because only those stumps that had already produced at least one sprout were originally chosen for the study, the stump sprout percents of figure 2 were adjusted to reflect the percent of stumps that, at the time of cutting, would be expected to produce sprouts. Unpublished data on white oak stumps of 30- to 70-year-old trees from

¹Unpublished study summaries by Paul S. Johnson, on file at Columbia, Missouri.

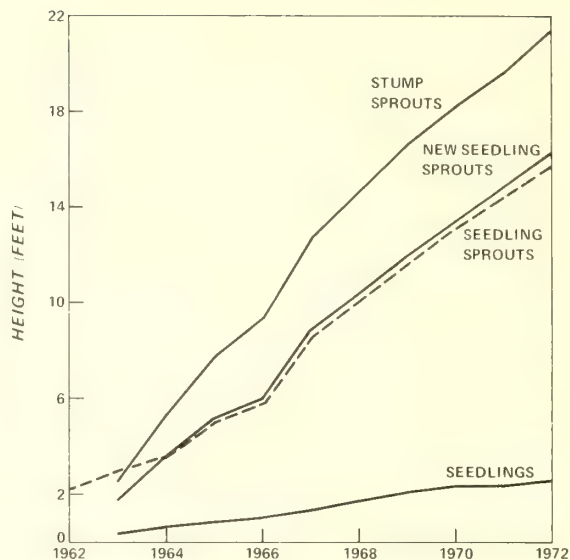


Figure 1.--Mean heights of the four types of reproduction, by year. Heights were measured in the fall of the year indicated. A late spring frost in 1966 reduced height growth for that year.

similar stands in the same area show this figure to be approximately 60 percent.

The survival and height data for seedling sprouts and new seedling sprouts were almost identical and were therefore combined in figure 2. The two categories were originally set up to see if new sprouts would outgrow existing stems, but 63 percent of the uncut seedling sprouts died back and resprouted at least once during the 10-year period, so at the end of that time the distinction between seedling sprouts and new seedling sprouts became almost meaningless. Moreover, the data indicated that new sprouts would grow at almost exactly the same rate as existing sprouts; the mean height of the uncut seedling sprouts that did not dieback and resprout was 15.7 feet at the end of the 10-year period, and the mean height of the seedling sprouts that did dieback and resprout was 16.0 feet.

There was a fairly strong correlation between height growth of the uncut seedling sprouts after release and size of the sprouts before release (fig. 3), which agrees with findings in Ohio and Illinois (Sander 1971, 1972). Figure 3 shows the relation between

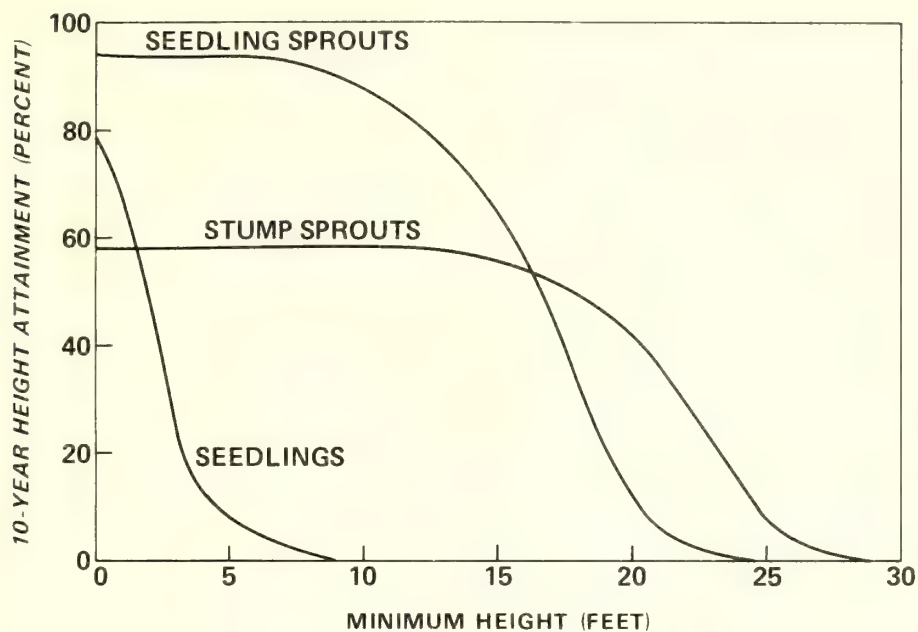


Figure 2.--Seedlings, seedling sprouts, and stump sprouts attaining the indicated minimum heights 10 years after the clearcut.

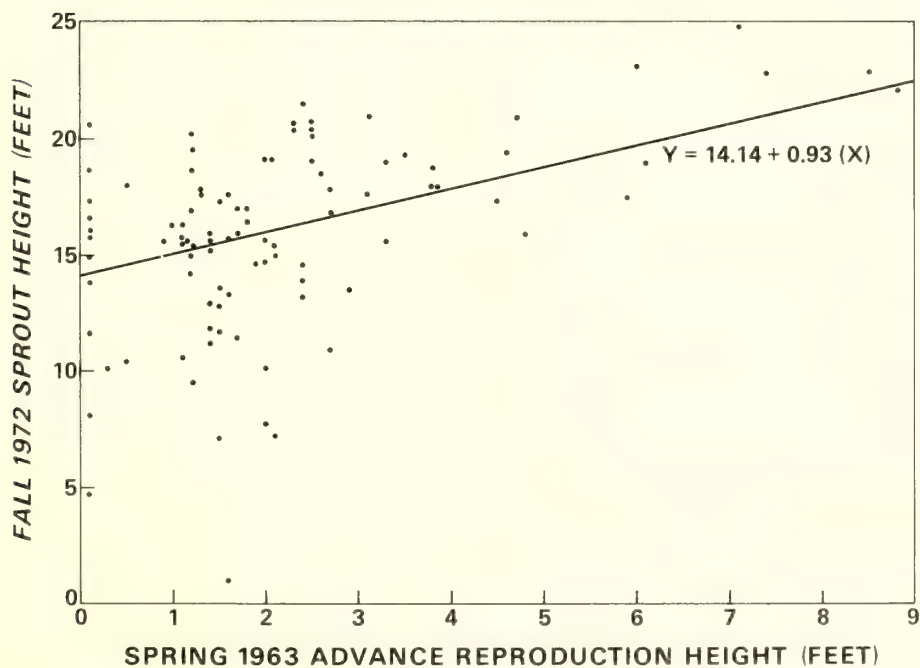


Figure 3.--Fall 1972 sprout height vs. spring 1963 advance reproduction height.

initial (preclearcut) and final (fall 1972) heights for the 95 surviving seedling sprouts. The regression in figure 3 was weighted ($w = 1.0/(9.0-X)^2$) to compensate for the greater variation in Y associated with the smaller values of X, and had a correlation coefficient of +0.83. The large amount of variation in final height among sprouts that were under 2 feet in height initially was presumably due to differences in vigor or size of the root systems.

The 10-year height attainment percents also varied for seedling sprouts of different original heights (fig. 4). In addition to their height advantage, stump sprouts and seedling sprouts also had much better form than the seedlings. More than 80 percent of the stump sprouts and seedling sprouts were in either the "good" or "fair" stem form categories in 1972, but less than 40 percent of the seedlings were in these categories.

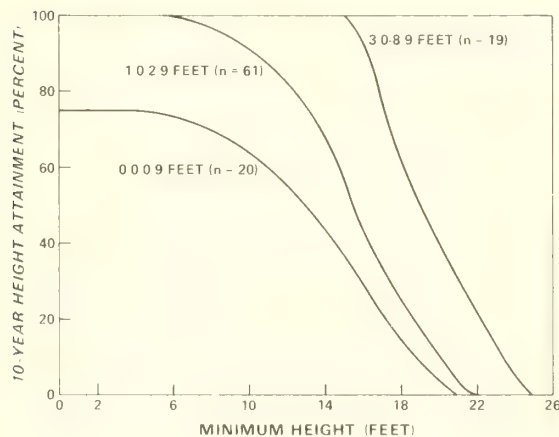


Figure 4.--Seedling sprouts that attained the indicated minimum heights 10 years after the clearcut, by three height classes at the time of the clearcut.

The stem form of uncut seedling sprouts improved after release, a trend also noted for oak seedling sprouts in West Virginia by Carvell (1967). Sixty-one percent of the surviving uncut seedling sprouts were in a higher form category at the end of the 10-year period that they were in the fall of the first year; 29 percent remained in the same category and 10 percent were in a lower category.

At the end of the 10-year period, the mean d.b.h. of the stump sprouts was 2.6 inches and that of the seedling sprouts and new seedling sprouts was 1.4 inches.

The mean number of live stump sprouts per stump at the end of the eighth year (the only year for which such data were available) was 2.2.

DISCUSSION AND SUMMARY

This study corroborates the findings of others (Beck 1970, Sander and Clark 1971, Sander 1972) that oak seedlings established at the time of clearcutting grow too slowly to be of value in stand reproduction, and that stump sprouts and the larger seedling sprouts are the most important sources of reproduction.

The similarity in height, survival, and form of the seedling sprouts and new seedling sprouts after 10 years leads to the conclusion that in regenerating white oak stands through clearcutting, it is not necessary to either protect seedling sprouts from logging damage or to deliberately knock back the existing tops to promote new sprouts.

Height attainment graphs (figs. 2 and 4) are particularly valuable in assessing oak reproduction because they combine measures of height distribution plus survival in a graph that can be used to make quantitative evaluations of the reproduction potential of stands before cutting. An example follows showing how height attainment percents can be used in evaluating stand reproduction.

Example

A 60-year-old white oak stand contains 300 overstory trees per acre; the understory contains 50 seedling sprouts ≥ 3.0 feet tall, 200 seedling sprouts 1.0 to 2.9 feet tall, 300 seedling sprouts ≤ 0.9 feet tall, and 100 new seedlings per acre. If the overstory is removed, the number of reproduction stems that will be present and at least 15 feet tall after 10 years can be computed by multiplying the 15-foot height-attainment percents (figs. 2 and 4) by the number of stumps, sprouts, or seedlings present at the time of the clearcutting (table 1).

The number of reproduction stems at any other minimum height 10 years after cutting can also be determined by substituting the appropriate height attainment percents from figures 2 and 4.

Table 1.--Sample computation of number of reproduction stems at least 15 feet tall 10 years after cutting

Reproduction type	15-foot height attainment	Sprouts or seedlings at time of cutting	Reproduction stems $\geq$ 15 feet tall 10 years after cutting
	Percent	No./acre	No.
Stump sprouts	² 0.56	300	168
Seedling sprouts $\geq$ 3.0 feet	¹ 1.00	50	50
1.0 to 2.9 feet	¹ .57	200	114
$\leq$ 0.9 feet	¹ .37	300	111
Seedlings	² .00	100	0
Total			443

¹ From figure 4.

² From figure 2.

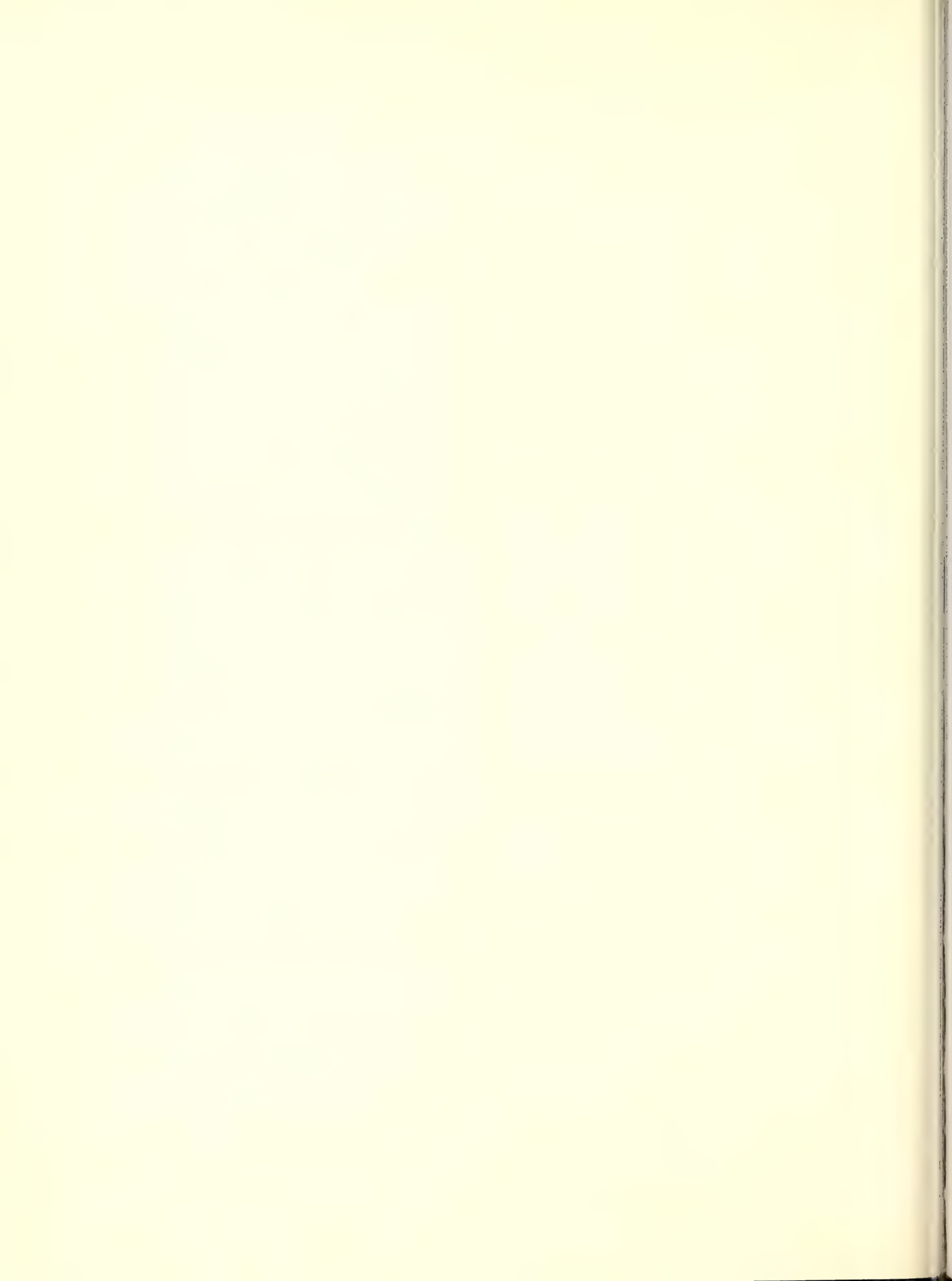
The actual minimum heights that should be used in any particular case and the interpretation of the results cannot be determined from this study, but would depend on the site index, the type of competition anticipated, and the management objectives.

In using the results of this study, it should be remembered that these data are from white oak only, and caution should be exercised in extending this information to other species, to overstory stands of other ages or to other types of reproduction.

Similar information for other oak species, information on seedling sprouts with roots less than 1 inch in diameter, and a procedure to account for spatial distribution of the reproduction will be needed to make complete evaluations of reproduction in mixed oak stands.

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McQuilkin, Robert A.

1975. Growth of four types of white oak reproduction after clearcutting in the Missouri Ozarks. USDA For. Serv. Res. Pap. NC-116, 5 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

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OXFORD: 181.51:232.324:176.1(778). *Quercus alba*.

KEY WORDS: *Quercus alba* L., seedlings, seedling sprouts, sprouts, regeneration, advance reproduction.

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accelerates

yellow birch

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CONTENTS

Growth Responses	3
Crown Development	3
Bole Quality	6
Discussion and Conclusion	7
Literature Cited	8
Appendix I	9
Appendix II	9

CROWN RELEASE ACCELERATES DIAMETER GROWTH AND CROWN DEVELOPMENT OF YELLOW BIRCH SAPPLINGS

Gayne G. Erdmann, Richard M. Godman, and Robert R. Oberg

Yellow birch (*Betula alleghaniensis* Britton) is one of the most valuable northern hardwood species but is decreasing in both growing-stock volume and quality of trees. Recent surveys show the volume in sawtimber-size trees has declined by about one-third in the last 10 years and the proportion of trees 18 inches and larger is limited (Sternitzke 1974). Most Lake States stands are second-growth stands that are still too young to produce the saw log sizes now required by industry.

In 1968 we began a series of yellow birch crown release studies in seedling- to small sawtimber-sized stands in Upper Michigan and northeastern Wisconsin. Specific objectives of these studies are to improve bole quality and increase survival as well as growth rates in existing stands so that saw log rotations can be shortened. Results from the sapling-size phase of this study are reported here. Crown development data in this study were supplemented with branch elongation measurements covering 1 year before release and 4 years after release. All results presented, except for branch elongation, are for 3 years after release.

Study trees were selected from a 16-year-old even-aged stand that became established following salvage operations after a tornado in 1953 (fig. 1). The area is located about 1 mile south of Lake Superior on the Bergland District of the Ottawa National Forest in the western Upper Peninsula.

Judging by the number of dead understory birch stems present, competition had been severe. Undoubtedly more birch had seeded in after salvage operations but their numbers had already been reduced by competing species and other causes. Stoeckeler and Arbogast (1948) reported a 21 percent reduction in the number of stems per acre (2,951 to 2,321) in an unmanaged 11-year-old northern hardwood stand after 8 years.

Although sugar maple was the most abundant species on the study area, it only accounted for 20 percent of the dominant stems. Most sugar maple stems were in codominant or lower



Figure 1.--The 16-year-old stand before release.

crown classes. The dominant saplings were primarily fast-growing-intolerant or moderately-tolerant species such as cherry, aspen, yellow birch, basswood, white ash, American elm, and paper birch. Scientific names and more details of original stand and soil conditions are included in Appendix I.

Five degrees of crown release were applied to 6 groups of both dominant and codominant 16-year-old yellow birch saplings, making a total of 60 study trees. Each group consisted of five saplings similar in stem and crown characteristics, diameters, and total heights. Initial diameters at

breast height (d.b.h.) ranged from 3.04 to 3.99 inches for dominant groups and from 2.17 to 2.91 inches for codominant groups. Heavy, moderate, light, very light, or no crown release treatments were randomly assigned to individual trees within each group. All trees whose crown edges were within the following distances of the released tree's crown were cut as follows: (1) very light release, 2.5 feet; (2) light release, 5 feet; (3) moderate release, 10 feet; and (4) heavy release, 15 feet (fig. 2). Cuttings were applied before leaves appeared in the spring of 1970.



Figure 2.--A moderately crown released 16- year-old sapling.

Diameters at breast height were measured annually to the nearest hundredth of an inch. Tree height, height to live crown, clear bole length, and the number and length of epicormic branches were measured before release and again at the end of the third growing season. Average crown diameters were initially obtained from eight crown radii measurements made around each study tree and from branch growth measurements made later. Foliage density was rated in 1969, 1970, and 1972 after birches were in full leaf.

Lateral branch elongation was measured on each tree for crown width change 1 year before release and 4 years after release. Four branches per tree were used with one branch being measured in each cardinal direction at the widest portion of the crown. Annual increments were measured to the nearest $\frac{1}{2}$ inch beginning from the branch tips toward the bole between terminal bud scars.

GROWTH RESPONSES

Diameter Growth

Crown release significantly (0.01 level) increased growth within each crown class (fig. 3, table 1); increases averaged about 36 percent the first year, 64 percent the second year, and 56 percent the third year for released over unreleased trees. Although actual diameter growth was greater for dominants, the percentage rate was higher for codominants. For the moderately and heavily released saplings, diameter growth averaged about 1.7 times more than the unreleased saplings during the 3-year period.

Diameter growth of dominants increased significantly with each successive degree of release through the moderate release treatment. The moderate and heavy treatments were equally effective in stimulating growth. In codominants, released trees responded better than unreleased trees, but differences in growth rates between various degrees of release were still not significant.

Height Response

Before release, dominant saplings averaged 28.4 feet tall; codominant saplings averaged 24.8 feet tall. During the 3-year period after release, height growth averaged 1.5 feet for both dominant and codominant saplings. Analyses of unadjusted 3-year

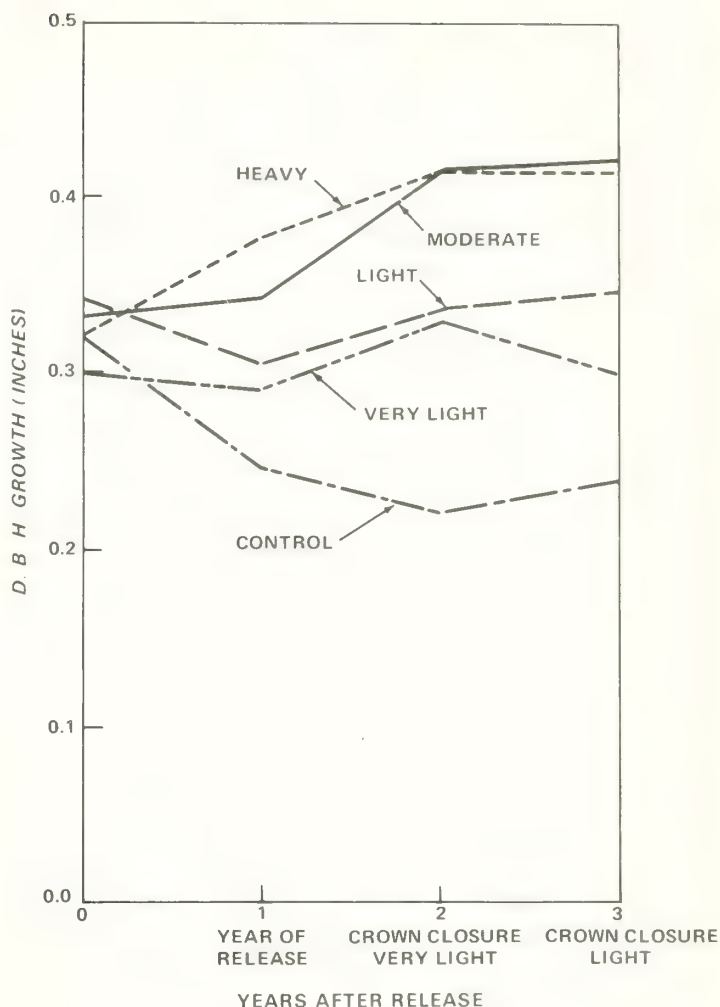


Figure 3.--Effect of crown release on mean annual diameter growth of sapling-size trees.

height growth data indicated that there were no significant differences in growth among the release treatments. When the height growth data for dominants were either adjusted for total sapling height before release or height growth the season before release, however, there was a significant difference favoring the unreleased dominants.

CROWN DEVELOPMENT

Crown Class

All dominant stems, except one unreleased tree, were still dominant after 3 years regardless of whether they were released or not.

Table 1.--Changes 3 years after crown release treatment in stem and crown characteristics of dominant and codominant yellow birch saplings

Characteristic	DOMINANT				
	Crown release treatment				
	: None : : (control) :	: Very : : light :	: Light :	: Moderate :	: Heavy :
Diameter (d.b.h.) (in.)	1.078d	0.90c	1.04b	1.26a	1.28a
Total height (ft)	5.1	4.2	3.3	4.4	4.0
Limb-free length ² (ft)	2.6a	0.5b	-0.4b	-1.1b	-0.9b
Live epicormic sprouts on butt log (No.)	1.0	2.8	1.5	3.7	2.0
Trees in dominant crown class (percent)	100	100	100	83	100
Trees in codominant crown class (percent)	0	0	0	17	0
Live crown length (ft)	2.4	3.7	3.4	5.4	4.9
Crown ratio (crown length/total height) (ratio)	.04b	.02b	.03b	.08a	.07a
Crown diameter (ft)	4.4b	4.1b	4.0b	5.5a	5.1a
Crown area (ft ²)	79b	70b	64b	96a	97a
Crown volume (length X area) (ft ³)	1923	1941	1790	2723a	2834a
Foliage density ³ (percent)	-2.1	4.2	10.4	16.7	14.6
Characteristic	CODOMINANT				
	Crown release treatment				
	: None : : (control) :	: Very : : light :	: Light :	: Moderate :	: Heavy :
Diameter (d.b.h.) (in.)	0.62	0.90a	0.95a	1.08a	1.11a
Total height (ft)	4.6	5.4	4.3	5.6	3.9
Limb-free length ² (ft)	2.2a	0.2b	0.1b	-2.0b	-0.8b
Live epicormic sprouts on butt log (No.)	4.0	2.5	2.3	5.3	4.8
Trees in dominant crown class (percent)	0	0	17	50	33
Trees in codominant crown class (percent)	83	100	83	50	67
Trees in suppressed crown class (percent)	17	0	0	0	0
Live crown length (ft)	1.6b	4.2a	4.3a	7.0a	4.7a
Crown ratio (crown length/total height) (ratio)	0.04b	0.06a	0.06a	0.11a	0.07a
Crown diameter (ft)	4.4	4.0	4.8	5.0	5.0
Crown area (ft ²)	67	63	67	75a	89a
Crown volume (length X area) (ft ³)	1323	1499	1524	1944a	2214a
Foliage density ³ (percent)	-10.4	-4.2	2.1	10.4	-2.1

¹Values followed by the same letter or without a letter in a row are not significantly different at least at the 0.05 level.

²Height from groundline to the first live limb on epicormic branch more than 24 inches long.

³Based on the percent of the main stem within the live crown obscured by foliage when viewed from two sides at one tree-length distance.

Release often improved the crown position of codominant saplings. After 3 years, 42 percent of those moderately or heavily released moved up to dominant positions. Half of this improvement was attributed to the elimination of competition from tall saplings; the remaining half to increased height growth after release. Crown positions of very lightly and lightly released codominants were not

improved by release. One of the six unreleased codominants dropped to an intermediate crown position because it had been outgrown by a neighbor.

Crown Length

Initially, codominants had about 65 percent of their total heights in live

crown; dominants had about 70 percent. Over the 3-year period, the proportion in live crown increased for released dominants and codominants but decreased for the unreleased trees. Crowded crowns of unreleased, very lightly released, and lightly released trees generally had less live crown length for their heights than moderately and heavily released trees.¹

Changes in crown length for codominants tended to increase with degree of release through the moderate release treatment, where crown length increases averaged 7 feet in the 3 years. For codominants, the differences in early changes in crown length were significantly better in released than unreleased trees (table 1). For dominants, trends in these changes appeared to be similar, but the differences between released and unreleased trees were not significant. These changes in live crown length were primarily caused by three factors: (1) higher natural branch mortality on unreleased trees, (2) longer retention of branches, and (3) development of some epicormic sprouts into branches on the more open-grown moderately and heavily released trees.

Changes in height² to the live crown for both dominants and codominants were significantly greater for unreleased than for released saplings (table 1). Live crowns of very lightly released codominants

¹Crown length is the length in feet from the tree's tip to the lowest live leaf on a branch that is part of the functioning crown.

²Height from groundline to the first live limb or epicormic branch more than 24 inches long.

also receded more than other released codominants; other very lightly released dominants as well as lightly released dominants and codominants were just beginning to recede after 3 years.

Crown Diameter

Before release, crown diameters of dominant and codominant saplings averaged 8.8 feet and 7.2 feet, respectively. In just 3 years diameters on both increased between 4 to 5 feet (table 1). Crown expansion was significantly more rapid on moderately and heavily released dominants than on less intensively released dominants. Similar trends were also apparent in the codominant saplings.

During the four growing seasons after release, branch elongation at the widest part of the crown was stimulated most by the moderate and heavy crown release treatments (table 2). Average lateral branch elongation in these two treatments was significantly greater than in the other treatments (fig. 4). Major differences in annual branch elongation between release treatments first occurred in the second season and again in the fourth growing season after release. Lateral branch growth was poor during the third season. The differences in the fourth growing season were related to poor growth following crown closure in the very lightly and lightly released treatments.

Branch elongation was similar on all sides (N, S, E, W) of both released and unreleased trees. Branches growing in openings elongated more rapidly than those closed with adjacent crowns. Annual branch elongation usually declined drastically

Table 2.--Mean lateral branch elongation of yellow birch saplings in relation to crown release treatment and growing positions in 1972 and 1973¹

(In inches/branch)

Crown release treatment	1972		1973	
	In openings	After crown closure	In openings	After crown closure
None (control)	7.38(4) ²	5.81(36)	2.50(4)	2.06(36)
Very light	7.00(2)	6.11(46)	10.00(2)	1.31(45)
Light	8.40(5)	5.70(43)	5.70(5)	2.70(43)
Moderate	6.75(45)	None	7.85(31)	7.80(15) ³
Heavy	6.67(48)	None	8.27(46)	6.75(2) ³

¹Annual lateral branch elongation at the widest part of the crown at lower canopy level.

²Figures in parentheses show number of branches on which average is based.

³Crowns just closing.

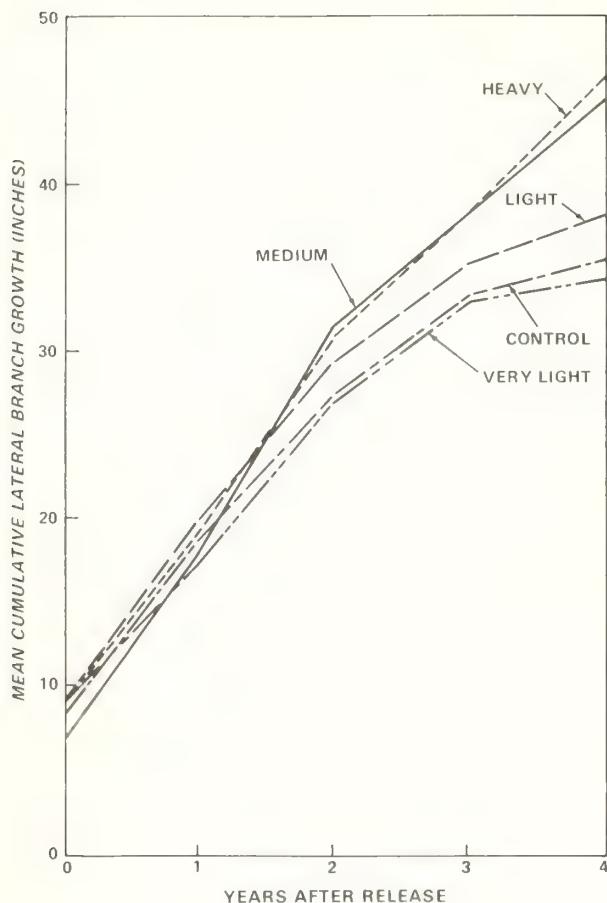


Figure 4.--Mean cumulative lateral branch elongation by years and crown release treatments for dominant and codominant birch saplings.

after crown closure. Lateral branch tips elongated less each season in unreleased and lightly released crowns and after the second season in the very lightly, moderately, and heavily released crowns. The very lightly released crowns closed almost immediately; most lightly released crowns closed within 3 years.

After 3 years, 33 percent of all moderately released saplings and 92 percent of all heavily released saplings were still completely free of crowding at the sides. Fifty-eight percent of the moderately released saplings still had at least two sides free of competition. At the present rate of growth six growing seasons would be required for all the crowns of moderately released saplings to close.

Crown Areas and Volumes

Crown areas (πr^2) and crown volumes (crown area $\times$ length) increased during the 3-year period. Changes in crown area were significantly (0.05 level) better for only moderately and heavily released dominants, but changes in crown volume were significantly better for both moderately and heavily released dominants and codominants (table 1). Buildups in crown volume were associated with the amount of additional growing space provided by the treatments. The greatest improvement in crown development occurred among moderately and heavily released trees.

Foliage Density

Almost every study tree had a crown with medium foliage density before release.³ After 3 years, crown foliage density ratings had improved on 46 percent of the released trees but no improvement was observed in crowns of unreleased trees. The ratings improved most among moderately released crowns; 75 percent of them increased in density, only 8 percent regressed (table 3). Most of the increases were attributed to the formation of new leaves on the newly elongating tips of existing branches and vigorous new terminal growth.

Table 3.--Change in foliage density by crown release treatment

(In percent of trees)

Foliage Density	Crown release				
	None (control)	Very light	Light	Moderate	Heavy
Remained the same	75	58	25	17	25
Improved ¹	0	17	50	75	42
Regressed ¹	25	25	25	8	33

¹Improved or regressed at least one-half foliage density class (12.5 percent).

BOLE QUALITY

Before release, study saplings averaged 16.7 live branches, 0.3 epicormic branches, and 21.9 dormant buds per lower 17-foot bole section. Heights to their first live branch averaged 8.8 feet above groundline.

Crown release delayed natural branch mortality and the normal progression of the

³See Appendix II for explanation of foliage density ratings.

base of the live crown up the tree. During the 3 years, significantly (0.01 level) more live limb-free length² was added to the boles of unreleased saplings than to released sapling boles. On unreleased saplings, branch mortality increased live limb-free bole lengths an average of 2.4 feet (to 11.0 feet); on released saplings, the development of epicormic branches decreased these lengths about 0.6 feet.

Bole sprouting was highly variable among individual trees; it ranged from 0 up to 24 new sprouts on 1 unreleased sapling during the 3-year period. Sprout numbers on the lower 17-foot bole sections of saplings increased from 0.3 to 3.2, but these increases did not differ by release treatment, crown class, or number of visible dormant buds present before release. Unreleased saplings had equally as many new sprouts as released saplings; codominants averaged one more new sprout per bole (four) than dominants. Bole face also had little effect on the numbers of new sprouts produced. Saplings averaged about 0.8 sprout per north, south, east, and west face.

Of the 194 new epicormic sprouts formed, 72 percent were short shoots (about 1 inch) with 1 or 2 leaves, 12 percent ranged between 3 and 21 inches long, and 12 percent were at least 24 inches long.

During the 3 years, 4 percent of the new and 74 percent of the old sprouts died. Nearly twice as many sprouts died on the north side (E-NE-N-NW) as on the south side (SE-S-SW-W) of the stems.

During the 3 years, sprout growth was affected by bole aspect. Sprouts on the south face of both released and unreleased saplings grew more than those on the more shaded north faces of sapling boles. Three-year sprout growth also increased significantly with each successive degree of release; the maximum was 7.45 inches for the heavily released saplings.

DISCUSSION AND CONCLUSION

Where the objective of management is to increase the number, size, and grade of yellow birch in developing second-growth hardwood stands, it will be necessary to release birches at an early age. Yellow birch is a moderately tolerant species that can survive for long periods under high

overhead cover but at greatly reduced growth rates and at considerable risk to mortality due to loss of vigor and increased susceptibility to infection from decay fungi. Previous experience in large openings on the Upper Peninsula Experimental Forest has shown that yellow birch can maintain an advantage in height over other species of the same age, but will fall behind sugar maple in height after 23 years (Eyre and Zillgitt 1953). This suggests that yellow birch should be released earlier for best responses.

Three-year results in our sapling stand suggest that birch trees will respond and benefit from release before 16 years of age. Better diameter growth responses would probably occur even earlier and should increase the number in the stand, particularly because dominant as well as codominant saplings have more ability to rapidly respond to increased growing space at these younger ages.

Growth responses in our sapling-, pole-, and small-saw log-sized crown release studies show that birches from 16 to 60 years old all respond to release. However, the best response is in the sapling stage. Sapling growth rates can be increased up to 4 inches per decade by cutting all stems whose crowns were within 10 to 15 feet of the released tree's crown. Growth rate on pole size trees can be doubled to a rate of over 2.5 inches in 10 years by release (Erdmann and Peterson 1972). Results in the pole and saw log studies also indicate that the present growth rates of 4 inches in 10 years in released saplings and over 2.5 inches in 10 years in poles will gradually fall off as tree diameter increases.

The question as to whether height growth of dominant saplings has been permanently or temporarily depressed by release remains to be answered. We believe that it will not be depressed at least up through the moderate release intensity.

Straight-stemmed trees with the fewest defects in their butt logs generally yield the largest volume of high grade material. The future quality of young trees can be improved most by reducing the number of surface defects caused by branches in the butt log section (Boyce and Schroeder 1963), because it usually contains the highest grade log in a tree and represents about 45 percent of the whole tree volume in northern hardwoods (Chase *et al.* 1970).

Counts of the total number of surface defects in the butt log section of 9 unreleased 65-year-old small saw log-sized yellow birches, showed that over 86 percent of the 4.2 surface defects found were branch related overgrown knots.⁴ Marquis (1967) reported that 25-year-old yellow birch, having potential crop tree quality, in New Hampshire already had an average live, limb-free bole length of 15 feet with only 2.0 live branches and 2.5 epicormic branches in their lower section.

Younger sapling-size trees with their lower crowns obviously have more branch-caused defects in their lower bole sections than older and larger sawtimber- and pole-size trees. Crown release in sapling-size trees delayed natural branch mortality but did not significantly increase bole sprouting, a potentially important cause of new defects in hardwood trees. Whether any of the 23 new or 2 old epicormic branches will persist and cause any reduction in final tree grades or lumber grades remains to be proven. Marquis (1969) does not consider short epicormic shoots with one or two leaves as important defects and most epicormic sprouts probably will disappear within 8 years as Stoeckeler and Arbogast (1948) found after thinning to a 5-foot radius in an 11-year-old northern hardwood stand.

In the sapling stage of stand development, characteristics such as diameter growth rate, length of clear bole, number and size of branches, and crown width, length, and density are also important and related to a tree's future bole quality potential. The main idea at this stage is to increase or at least maintain the number of better quality birch stems in the upper canopy. Although the greatest improvement in final hardwood log quality can be made by reducing the number of branch-caused defects outside the heart center of the butt log (Boyce and Schroeder 1963), some additional increase in future valuable birch volumes should be possible by eliminating low forks at the time of release in saplings. This is especially true on the more widely released trees because forks tend to persist on more open-grown trees and merchantable heights in saw log-sized birches are often terminated by forks. By removing forks early, more merchantable length and

resulting volume can be obtained without any reduction in upper log diameters.

It is still too early to determine whether a single release treatment will increase the numbers of birch or affect the quality of the final stand. However, results are promising. The 10-foot crown release treatment increased the stem and crown vigor of birch saplings and improved the crown positions of half of the codominant saplings in less than 3 years. Now these released saplings have a much better chance of surviving sugar maple competition than the unreleased saplings. Their crown edges still were free to grow at the end of 3 years and should be free of side competition for at least 2 years longer. The narrower crown release treatments were too short-lived, and growth rate in the 2.5 foot crown-released saplings dropped off the year after crown closure. Expected differences in diameter growth rate between 5-foot, 10-foot, and 15-foot release treatments should favor the wider release treatments following earlier crown closure on the 5-foot treatment. Growth responses are expected to last at least 10 years in the wider 10- and 15-foot crown release treatments.

If these trends continue, birch saw- and veneer-log rotations in the Lake States can be cut in half by doubling diameter growth rates of saplings and poles in existing stands through crown release.

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APPENDIX I

Before release the densely stocked uniform-sized stand contained 3,480 trees (0.6 inches d.b.h. and larger) with 49 square feet of basal area per acre. Species composition averaged 81 percent sugar maple (*Acer saccharum* Marsh.), 10 percent yellow birch, 6 percent ironwood (*Ostrya virginiana*) and 3 percent other

northern hardwood species consisting primarily of white ash (*Fraxinus americana* L.), basswood (*Tilia americana* L.), and aspen (*Populus* spp.), with an occasional cherry (*Prunus serotina* Ehrh. and *Prunus pensylvanica* L. f.), American elm (*Ulmus americana* L.) and paper birch (*Betula papyrifera* Marsh.).

The stand occupies a broad ridgetop, elevation 1,580 feet, that slopes gently (0 to 6 percent) to the northeast. The soil is well-drained Iron River silt loam, which is acid in reaction to a depth of several feet and underlain by a weak fragipan. Site index for yellow birch was estimated to be about 60 feet at age 50.

APPENDIX II

Foliage density ratings were based on the average percent of the main stem within the tree's live crown that was obscured by foliage when viewed from two sides at one tree-length distance as follows: dense (87.5 or more), medium-dense (75 to 87.5), medium (62.5 to 75), fair-medium (50 to 62.5), fair (37.5 to 50), and poor (37.5 or less).

Erdmann, Gayne G., Richard M. Godman, and Robert R. Oberg.

1975. Crown release accelerates diameter growth and crown development of yellow birch saplings. USDA For. Serv. Res. Pap. NC-117, 9 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

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KEY WORDS: crown thinning, crop tree, crown classes, stem quality.

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Vertebrate animal populations of the McCormick Forest



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1975

VERTEBRATE ANIMAL POPULATIONS OF THE MC CORMICK FOREST

William L. Robinson and J. Kirwin Werner

CONTENTS

I. BIRDS AND MAMMALS	1
Methods	1
Results	3
Acknowledgment	16
Literature Cited	16
II. AMPHIBIANS AND REPTILES	18
Materials and Methods	18
Results	19
Discussion	23
Acknowledgments	25
Literature Cited	25

CYRUS H. McCORMICK TRACT

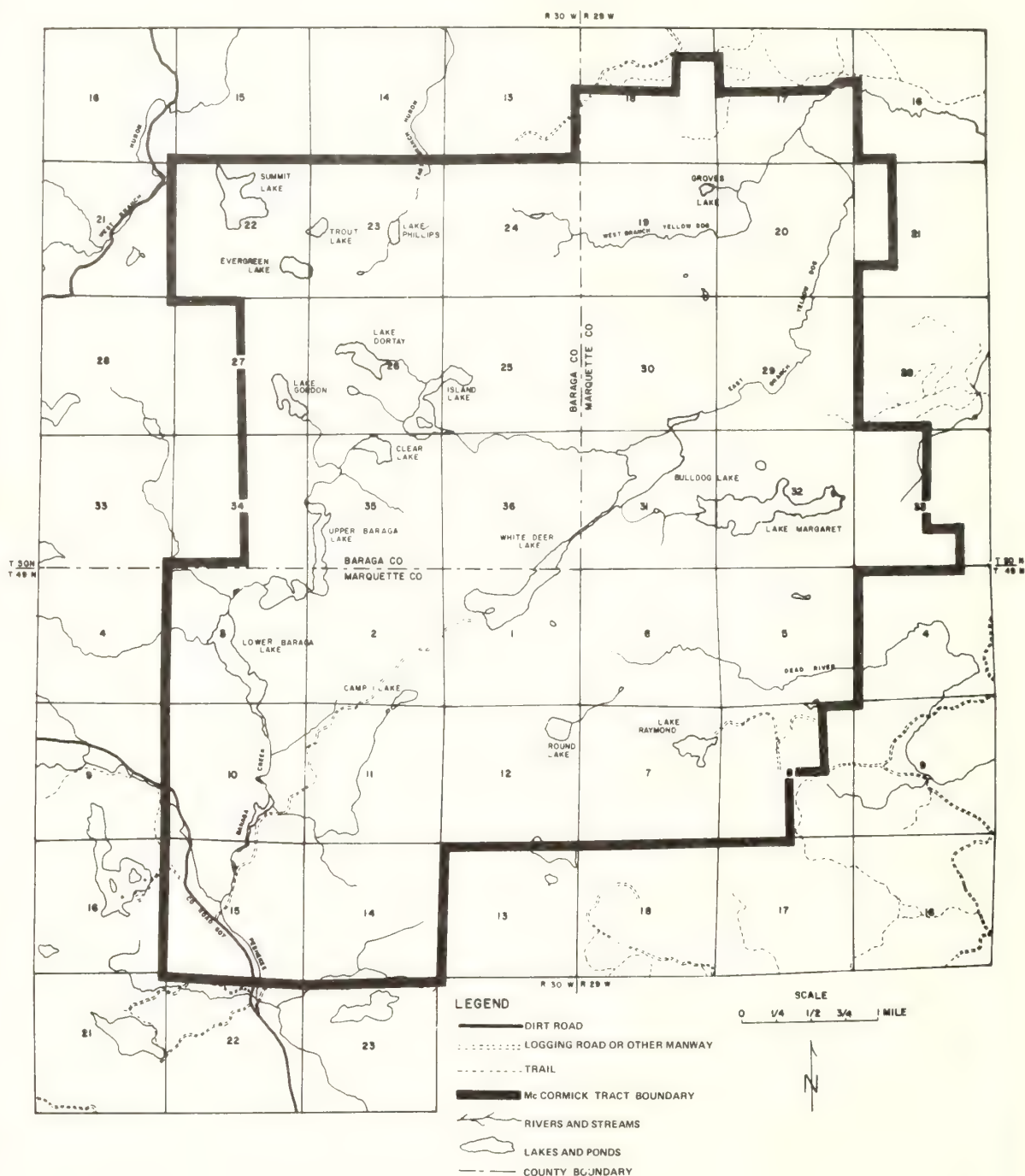


Fig. 1.--Map of the Cyrus H. McCormick Experimental Forest.

BIRDS AND MAMMALS

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ABSTRACT.--Birds and mammals were inventoried on a 17,124-acre forested tract recently acquired by the USDA Forest Service in the Upper Peninsula of Michigan. An annotated list was made of the 109 species of birds and 33 species of mammals observed. Population densities were estimated for loons (*Gavia immer*), ruffed grouse (*Bonasa umbellus*), beavers (*Castor canadensis*), and small mammals in various forest habitats. Comparisons with the findings of other workers and a discussion of birds and mammals found elsewhere in Upper Peninsula but not in the McCormick Forest are also included.

In recent years there has been increasing awareness of the interdependence of all the various elements of the biosphere. The impact of man's activities has been global, and in many cases overwhelming. Yet there remain scattered enclaves in which the influence of man and his machinery has been minimal.

In the forested parts of the eastern United States these enclaves are rare and valuable. Their value lies in their capacity to provide us not only with inspiration but also with information as to how plant and animal communities function in the absence of extensive human intervention. They may serve as controls in the huge experiment of manipulation that man is carrying out on the Earth and its atmosphere. The McCormick Forest is one of these enclaves, one which may serve us best as a natural laboratory--a standard by which changes in the world around it can be compared.

A first step in understanding the functioning of a community is an inventory of its participants. This paper is a report on such an inventory in the McCormick Forest, carried out in 1972 and 1973. The objectives of the inventory were to gather information on the birds and mammals present in the McCormick Forest, determine their approximate densities, and find out what habitats they occupy.

The McCormick Forest is a 17,124-acre tract located in northwestern Marquette and eastern Baraga Counties in the Upper

Peninsula of Michigan. It was donated in 1968 to the USDA Forest Service by the late Gordon McCormick whose family had purchased the tract piecemeal from about 1900 to 1936. Little disturbance has occurred since 1936. The McCormick Forest includes 28 lakes and numerous small streams. The topography is rugged with rock outcrops that rise to an elevation of 1,900 feet. A variety of vegetation types occur, ranging from sphagnum bogs to mature upland hardwoods dominated by sugar maple (*Acer saccharum*). Between these extremes are spruce (*Picea mariana*) and cedar (*Thuja occidentalis*) swamps, white birch (*Betula papyrifera*) - aspen (*Populus tremuloides*) stands, and a burned-over area consisting of sparse spruce trees (*Picea glauca* and *P. mariana*) and blueberries (*Vaccinium* spp.). The mature hardwoods also contain some large white pines (*Pinus strobus*), yellow birch (*Betula alleghaniensis*), hemlock (*Tsuga canadensis*), and some balsam fir (*Abies balsamea*). Metzger (1973) described the vegetation of the 3,675-acre natural area in the northeast corner of the forest.

METHODS

Field work began in June 1972 and continued through April 1974. Observations of birds and mammals made in previous years were obtained by consulting persons familiar with the area and records of the Michigan Department of Natural Resources. Because there are probably over 200 species of birds and 45 species of mammals in the

McCormick Forest, it would be difficult and time consuming to obtain quantitative data on the densities of all of them. It was thus desirable to use extensive methods for most species and intensive methods for species that are of particular interest or that lend themselves well to quantitative sampling.

Extensive Methods

Extensive methods were designed to obtain a broad coverage of the tract to learn what birds and mammals were present, without regard for estimating population densities. These methods consisted of observing animals while traveling by automobile, foot, canoe, and airplane.

About 1.5 miles of County Road 607 cuts across the southwest corner of the tract and a dirt road runs from there 3.4 miles into the abandoned McCormick lodge on White Deer Lake (fig. 1). During travel on these roads records were kept of all birds and mammals seen from the car. A total of 214 miles were traveled by auto in the tract in 1972 and 284 miles in 1973. County Road 607 was plowed in winter but the road to the lodge was not.

In addition to animals seen within the McCormick Forest, records were also kept of all birds and mammals seen on County Road 607 while traveling by car the 8.8 miles between the Forest boundary and U.S. Highway 41.

We traveled by canoe during both day and night and kept records of the animals seen. In the daytime we paddled about 42 miles in 21 hours on the following lakes: Bulldog, Lower Baraga, Margaret, Summit, Upper Baraga, and White Deer. We canoed at night with the aid of a hand-held spotlight attached to a 12-volt car battery. The bowman handled the light, searching the shoreline for animals, while the sternman paddled quietly. About 20 miles of shoreline were traveled by canoe at night in 17 hours. All mammals and birds seen or heard and identified were noted. The lakes covered by night were the Baraga Lakes, Bulldog, and White Deer.

About 148 miles were walked on bare ground in the tract from April to October, and 70 miles were snowshoed or skied from November to March.

Two flights were made over the tract to count beaver dams in November 1972, and to locate deer or deer trails in March 1973. Active beaver colonies were also noted from ground observation of dams, fresh cuttings, and the animals themselves.

Chance sightings of birds and mammals were recorded and sightings by other competent observers were also used.

Intensive Methods

Attempts were made to obtain quantitative information on populations of small mammals in five habitat types (table 1). The usual scheme was to set a 7 by 4 grid of live traps¹ spaced 50 feet (15.2 m) apart for 4 nights. All live mice and chipmunks caught were ear tagged and released. Immediately after this 4 night period, pitfalls were dug in the center of each 50-foot square enclosed by the trap locations, resulting in a 6 by 3 grid of pitfalls. A metal can 10 inches in diameter and 12.5 inches deep was sunk into each pitfall. Chipmunks could escape by jumping out of the cans but it is unlikely that any mice or shrews did. The objective of the pitfalls was two-fold. First they are effective in capturing shrews (Buckner 1955, Coulombe and Banta 1964), and second they provide a way of capturing small rodents that eliminates the bias in mark-recapture data caused by avoidance or attraction of baited traps (Kott 1965).

In 1973 considerable effort was spent in determining loon populations and their reproductive efforts and success. Each lake was visited several times and intensively searched for nests if loons were found. The hatching and rearing success of loons was followed through the month of July.

Ruffed grouse populations were estimated by recording sighting distances and perpendicular distance of each bird from the line of walk, according to the formulas of Kelker (1945) and King (Leopold 1933), recently

¹ Some were specially designed and provided by Richard Buech, USDA Forest Service, Rhinelander, Wisconsin, and some were Havahart No. 0. Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.

Table 1.--Small mammal trapping dates and locations

Dates	Trap nights	Type of trap ¹	Type of habitat	Location
July 7 to 17, 1972	198	P	Bog	NW $\frac{1}{4}$ of NW $\frac{1}{4}$ Sec. 11. T49N R30W
July 17 to 21, 1972	112	L	Hardwood-pine	SW $\frac{1}{4}$ of SE $\frac{1}{4}$ Sec. 2. T49N R30W
July 21 to 25, 1972	72	P	Hardwood-pine	do.
July 24 to 29, 1972	140	L	Spruce barrens	NE $\frac{1}{4}$ of NW $\frac{1}{4}$ Sec. 15. T49N R30W
July 29 to Aug. 2, 1972	90	P	Spruce barrens	do.
July 31 to Aug. 4, 1972	140	L	Spruce swamp	SW $\frac{1}{4}$ of NW $\frac{1}{4}$ Sec. 15. T49N R30W
Aug. 4 to 11, 1972	144	P	Spruce swamp	do.
Aug. 7 to 11, 1972	112	L	White birch-aspen	E $\frac{1}{2}$ of NE $\frac{1}{4}$ Sec. 15. T49N R30W
May 21 to 25, 1973	90	P	Spruce barrens	NE $\frac{1}{4}$ of NW $\frac{1}{4}$ Sec. 15. T49N R30W
May 21 to 25, 1973	90	P	Spruce swamp	do.
May 28 to June 3, 1973	90	P	Hardwood-pine	SW $\frac{1}{4}$ of SE $\frac{1}{4}$ Sec. 2. T49N R30W
May 28 to June 3, 1973	90	P	Bog	SE $\frac{1}{4}$ of SE $\frac{1}{4}$ Sec. 2. T49N R30W
July 9 to 19, 1973	198	P	Hardwood-pine	NE $\frac{1}{4}$ of NE $\frac{1}{4}$ Sec. 20. T50N R29W

¹ P = pitfall; L = live-trap.

own to be two of the most reliable estimating methods (Robinette *et al.* 1974). The formulas are:

Kelker: $N = N^1 A/2 L D$, and

King: $N = n A/2 L R$.

Where: N = estimated animal population; n = number of animals seen; N^1 = number of animals seen within 2D; D = width of a strip within which all animals are believed to be seen (25 feet for ruffed grouse); A = area sampled; L = length of census lines; and R = mean sighting distance.

RESULTS

Birds

Bird species seen in the McCormick Forest numbered 109 (table 2). Most of the species seen along County Road 607 within

9 miles of the McCormick Forest, probably also occur within the Forest. These include the goshawk, Cooper's hawk, brown thrasher (observed in the tract by Hermann), the red crossbill and the starling. A goshawk nest was found between Bulldog and Margaret Lakes in 1969.² Two starlings were seen about 9 miles south of the McCormick Forest. They are also found near Ives Lake 10 miles north. Because of the nearly unbroken forest habitat on the McCormick Forest, however, the starling probably does not occur there. Spruce grouse were reported from a conifer area 8 miles west of the McCormick Forest and they are common on the Yellow Dog Plains, 3 miles north, but none was found in the McCormick Forest during the present study.

² Reported by Duane Campbell, Fisheries Biologist, Ottawa National Forest.

Table 2.--Birds seen in the McCormick Forest

Species	: Present : study	: : Hermann ¹	: Status ² and : comments
Common loon ³ (<i>Gavia immer</i>)	X	X	Abundant
Pied-billed grebe (<i>Podilymbus podiceps</i>)	X	--	Uncommon
Great blue heron (<i>Ardea herodias</i>)	X	X	Common
American bittern (<i>Botaurus lentiginosus</i>)	X	X	Uncommon
Canada goose (<i>Branta canadensis</i>)	X	--	Migrants only passing over
Mallard ³ (<i>Anas platyrhynchos</i>)	X	--	Common-nesting
Black duck ³ (<i>Anas rubripes</i>)	X	--	Common-nesting
Wood duck (<i>Aix sponsa</i>)	X	--	Common-nesting
Ring-necked duck (<i>Aythya collaris</i>)	X	--	Uncommon-nesting
Common goldeneye (<i>Bucephala clangula</i>)	X	--	Migrants only - feeding in lakes
Bufflehead (<i>Bucephala albeola</i>)	X	--	Migrants only - feeding in lakes
Hooded merganser (<i>Lophodytes cucullatus</i>)	X	--	Common-nesting
Common merganser (<i>Mergus merganser</i>)	X	--	Abundant-nesting
Red-breasted merganser (<i>Mergus serrator</i>)	--	X	Rare
Goshawk ^{3,4} (<i>Accipiter gentilis</i>)	--	--	Rare
Sharp-shinned hawk (<i>Accipiter striatus</i>)	X	X	Uncommon
Cooper's hawk (<i>Accipiter cooperii</i>)	--	--	Rare
Red-tailed hawk (<i>Buteo jamaicensis</i>)	X	--	Common-nesting
Red-shouldered hawk (<i>Buteo lineatus</i>)	--	X	Rare
Broad-winged hawk (<i>Buteo platypterus</i>)	X	--	Common-nesting
Marsh hawk (<i>Circus cyaneus</i>)	X	--	Uncommon
Osprey ³ (<i>Pandion haliaetus</i>)	X	X	Uncommon
Sparrow hawk (<i>Falco sparverius</i>)	X	X	Uncommon
Ruffed grouse ³ (<i>Bonasa umbellus</i>)	X	X	Common-nesting
Sandhill crane (<i>Grus canadensis</i>)	X	--	Rare-one seen flying over
American coot (<i>Fulica americana</i>)	--	X	Rare
American woodcock ³ (<i>Philohela minor</i>)	X	--	Common-nesting

(Table 2 cont. on next page)

(Table 2 cont.)

Species	: Present : Study	: : Hermann ¹	: Status ² and : comments
Common snipe (<i>Capella gallinago</i>)	X	--	Rare
Spotted sandpiper (<i>Actitis macularia</i>)	X	X	Common-nesting
Solitary sandpiper (<i>Tringa solitaria</i>)	X	--	Rare-one seen on Groves Lake, Aug. 2, 1972
Herring gull (<i>Larus argentatus</i>)	X	X	Common
Black-billed cuckoo (<i>Coccyzus erythrophthalmus</i>)	--	X	Rare
Great-horned owl (<i>Bubo virginianus</i>)	--	X	Rare
Barred owl (<i>Strix varia</i>)	X	--	Common
Whip-poor-will (<i>Caprimulgus vociferus</i>)	X	--	Uncommon
Nighthawk (<i>Chordeiles minor</i>)	X	X	Common
Chimney swift (<i>Chaetura pelagica</i>)	X	X	Common
Ruby-throated hummingbird (<i>Archilochus colubris</i>)	X	X	Uncommon
Belted Kingfisher (<i>Megasceryle alcyon</i>)	X	X	Common
Common flicker (<i>Colaptes auratus</i>)	X	X	Common
Pileated woodpecker (<i>Dryocopus pileatus</i>)	X	X	Uncommon
Yellow-bellied sapsucker (<i>Sphyrapicus varius</i>)	X	X	Common-nesting
Hairy woodpecker ³ (<i>Dendrocopos villosus</i>)	X	X	Common
Downy woodpecker (<i>Dendrocopos pubescens</i>)	X	X	Common
Black-backed woodpecker (<i>Picoides arcticus</i>)	X	--	Uncommon
Eastern kingbird (<i>Tyrannus tyrannus</i>)	X	X	Common-nesting
Alder flycatcher (<i>Empidonax alnorum</i>)	X	X	Common
Eastern phoebe (<i>Sayornis phoebe</i>)	X	X	Common-nesting
Least flycatcher (<i>Empidonax minimus</i>)	X	X	Common
Eastern wood pewee (<i>Contopus virens</i>)	X	X	Common
Olive-sided flycatcher (<i>Nuttallornis borealis</i>)	X	--	Uncommon
Tree swallow (<i>Iridoprocne bicolor</i>)	X	X	Common
Barn swallow (<i>Hirundo rustica</i>)	X	X	Common-nesting
Purple martin (<i>Progne subis</i>)	X	X	Rare
Gray jay ³ (<i>Perisoreus canadensis</i>)	X	--	Uncommon

(Table 2 cont. on next page)

(Table 2 cont.)

Species	Present study	Hermann ¹	Status ² and comments
Blue jay ³ (<i>Cyanocitta cristata</i>)	X	X	Common
Common raven ³ (<i>Corvus corax</i>)	X	X	Common
Common crow ³ (<i>Corvus brachyrhynchos</i>)	X	X	Uncommon
Black-capped chickadee ³ (<i>Parus atricapillus</i>)	X	X	Common
Boreal chickadee ³ (<i>Parus hudsonicus</i>)	X	--	Uncommon
Red-breasted nuthatch (<i>Sitta canadensis</i>)	X	X	Common
Brown creeper (<i>Certhia familiaris</i>)	X	X	Uncommon
Winter wren (<i>Troglodytes troglodytes</i>)	X	X	Common
Catbird (<i>Dumetella carolinensis</i>)	--	X	Rare
Brown thrasher ^{3,4} (<i>Toxostoma rufum</i>)	--	X	Uncommon
Robin (<i>Turdus migratorius</i>)	X	X	Abundant-nesting
Hermit thrush (<i>Catharus guttatus</i>)	X	X	Common
Swainson's thrush (<i>C. ustulatus</i>)	X	X	Common-nesting
Veery (<i>C. fuscescens</i>)	X	X	Common-nesting
Golden-crowned kinglet (<i>Regulus satrapa</i>)	X	X	Common
Ruby-crowned kinglet (<i>Regulus calendula</i>)	X	X	Uncommon
Cedar waxwing (<i>Bombycilla cedrorum</i>)	X	X	Common
Starling ^{3,4} (<i>Sturnus vulgaris</i>)	--	--	Absent on Forest
Solitary vireo (<i>Vireo solitarius</i>)	X	X	Common
Red-eyed vireo (<i>Vireo olivaceus</i>)	X	X	Common
Black and white warbler (<i>Mniotilta varia</i>)	X	--	Uncommon
Tennessee warbler (<i>Vermivora peregrina</i>)	--	X	Uncommon
Nashville warbler (<i>Vermivora ruficapilla</i>)	X	X	Common
Northern parula (<i>Parula americana</i>)	X	X	Common
Yellow warbler (<i>Dendroica petechia</i>)	X	X	Uncommon
Magnolia warbler (<i>Dendroica magnolia</i>)	X	X	Common
Black-throated blue warbler (<i>Dendroica caerulescens</i>)	X	X	Uncommon
Yellow-rumped warbler (<i>Dendroica coronata</i>)	X	X	Common

(Table 2 cont. on next page)

(Table 2 cont.)

Species	: Present : study	: Hermann ¹	: Status ² and : comments
Black-throated green warbler (<i>Dendroica virens</i>)	X	X	Common
Blackburnian warbler (<i>Dendroica fusca</i>)	X	X	Common
Chestnut-sided warbler (<i>Dendroica pensylvanica</i>)	X	X	Common
Oven-bird (<i>Seiurus aurocapillus</i>)	X	X	Abundant
Northern waterthrush (<i>Seiurus noveboracensis</i>)	--	X	Uncommon
Mourning warbler (<i>Oporornis philadelphia</i>)	X	X	Common
Yellowthroat (<i>Geothlypis trichas</i>)	X	X	Uncommon
American redstart (<i>Setophaga ruticilla</i>)	--	X	Uncommon
Red-winged blackbird (<i>Agelaius phoeniceus</i>)	X	X	Common
Common grackle (<i>Quiscalus quisculus</i>)	X	X	Common
Brown-headed cowbird (<i>Molothrus ater</i>)	--	X	Uncommon
Scarlet tanager (<i>Piranga olivacea</i>)	X	X	Uncommon
Rose-breasted grosbeak (<i>Pheucticus ludovicianus</i>)	X	X	Common
Evening grosbeak (<i>Hesperiphona vespertina</i>)	X	X	Common
Purple finch (<i>Carpodacus purpureus</i>)	X	X	Uncommon
Pine grosbeak (<i>Pinicola enucleator</i>)	X	--	Uncommon
Pine siskin (<i>Spinus pinus</i>)	--	X	Uncommon
American goldfinch (<i>Spinus tristis</i>)	X	X	Uncommon
Red crossbill (<i>Loxia curvirostra</i>)	--	--	Uncommon
Vesper sparrow (<i>Poecetes gramineus</i>)	X	--	Rare
Slate-colored junco (<i>Junco hyemalis</i>)	X	X	Common
Chipping sparrow (<i>Spizella passerina</i>)	X	X	Abundant
White-throated sparrow (<i>Zonotrichia albicollis</i>)	X	X	Abundant-nesting
Swamp sparrow (<i>Melospiza georgiana</i>)	--	X	Uncommon
Song sparrow (<i>Melospiza melodia</i>)	X	X	Common-nesting
Snow bunting (<i>Plectrophenax nivalis</i>)	X	--	Uncommon migrant in fall

¹ From list of F. J. Hermann, June 18-21, 1971.

² *Abundant*--very likely to be seen in large numbers in its habitat at the proper season; *common*--may be seen most of the time in the proper habitat in the proper season; *uncommon*--may be seen quite regularly in small numbers in the proper habitat and season; and *rare*--may be seen only on a small percent of trips and habitat is restricted.

(Robbins et al. 1966)

³ Discussed in text.

⁴ Species seen only on County Road 607 leading to McCormick Forest.

Undoubtedly many species of birds that occur in the McCormick Forest went unobserved. Concerted effort by large numbers of people, especially during migration seasons, would probably reveal perhaps 50 additional species. Rice³ has recently compiled a list of 225 species of birds sighted since 1900 at the Huron Mountain Club 8 to 12 miles north of the McCormick Forest. Rice suggests that it is possible for a single observer at the Huron Mountain Club to record 120 to 150 species in a summer season. By comparison, our list of 109 for 2 seasons on the McCormick Forest appears scanty. Because the Huron Mountain Club area borders on Lake Superior, however, and contains an abandoned dairy pasture, more bird habitats and species occur there than on the relatively uniformly forested and landlocked McCormick Forest.

In 1973 intensive efforts were made to census populations of the common loon and their reproductive success. Four nests were found; one each on Summit, Upper Baraga, Bulldog, and Raymond Lakes. Adult loons were also seen on Lake Margaret and Island Lake but they apparently did not nest. The nest on Upper Baraga Lake, which contained one egg, was incubated faithfully but did not hatch. The other three nests each contained two eggs and all of them hatched. All six young were still alive in mid-August. Thus a population of 11 to 12 adult loons produced 6 offspring on the McCormick Forest in 1973. The previous year an estimated 13 adults produced 4 young. During the 2 years the adult:young ratio was about 25:10 or 2.5:1. This compares favorably with a ratio of 4:1 reported by Olson and Marshall (1952) from northern Minnesota and 7.1:1 in British Columbia (Olson and Marshall 1952). The breeding range of the loon in Michigan has been rapidly restricted in recent years because of development of lakeshores and increased disruption of nesting areas by people engaged in recreation. It would appear that the isolated and undisturbed character of the McCormick Forest contributes substantially to the breeding success of its loon population.

Upper Michigan lies in a transitional area between the range of the black duck to the east and the mallard to the west (Johnston 1970). Seven sightings of mallards with two broods were made and five sightings of black ducks with two broods were made in

the McCormick Forest, adding support to Johnston's (1970) contention that mallards slightly outnumber black ducks in Marquette County.

No osprey was seen in 1972, but in 1973 several sightings of a lone bird were made at Bulldog Lake and one sighting was made at Summit Lake. Hermann reported seeing an osprey in 1971.

In the summer of 1972, seven adult ruffed grouse were seen⁴ in 35.5 miles of walking for an average of one adult grouse seen per 5.1 miles. In summer of 1973, 16 adult grouse were seen in 104 miles of walking for an average of 1 per 6.5 miles. In the winter of 1972-73, 11 grouse were seen in 70 miles of walking, or 1 per 6.4 miles. In 1972, 5 of the 7 adult ruffed grouse seen had broods, while in 1973 only 6 of the 16 adults had broods. Population density in 1972 as estimated by the King method (Robinette *et al.* 1974) was 17.3 adults per square mile while in 1973 it was 15.0 per square mile. Estimates made by the Kelker method were 30.2 and 18.1 birds per square mile for 1972 and 1973, respectively. These densities compare with 17 to 31 per square mile in the Adirondack Mountains of New York (Bump *et al.* 1947), 5 to 54 per square mile in Lower Michigan (Palmer and Bennett 1963), and 27 to 40 per square mile in Alberta (Rusch and Keith 1971), to pick a few examples. Thus, ruffed grouse populations are comparable to those in other areas.

On the evening of May 31, 1973, nine singing male woodcock were counted on a 1.8-mile route extending from the spruce barrens along the Peshekee River down County Road 607 and up the McCormick Road along Baraga Creek. About nine woodcock were seen performing in mid-May on the spruce barrens.⁵

In summer, six hairy and five downy woodpeckers were sighted, indicating a nearly even ratio of the two species. In winter, however, the downy was more prevalent, with 18 downy to only 7 hairy woodpeckers seen.

³ R. A. Rice. Unpublished revised checklist, Huron Mountain Birds. 22 p. Huron Mountain Club, Big Bay, Mich. 1974.

⁴ In this case and others similar throughout the paper, some animals may have been "seen" or "sighted" more than once.

⁵ Reported by James Haveman.

Of the 2 jays recorded, sightings of the blue jay outnumbered those of its northern relative, the gray jay, by 16 to 1 in the summer. In winter, however, we saw three gray jays but no blue jays. Although the blue jay is found in Marquette County commonly in winter, it apparently associates closely with man during that season.

Black-capped chickadees outnumbered boreal chickadees in summer with 9 sightings to 3 and in winter by 26 to 2.

Ravens were far more commonly seen than crows, with 6 summer and 17 winter sightings of ravens to only 3 summer sightings of crows.

Eleven species of birds were seen in the winter. Species and numbers seen were: black-capped chickadee (26), downy woodpecker (18), raven (17), ruffed grouse (11), hairy woodpecker (7), pileated woodpecker (3), gray jay (3), boreal chickadee (2), black-backed woodpecker (1), red-breasted nuthatch (1), and brown creeper (1). A goshawk and a blue jay were seen on County Road 607 in winter several miles south of the McCormick Forest.

Mammals

Insectivora

Masked shrew (Sorex cinereus).--The masked shrew was found in all habitat types in densities of up to 11 per acre⁶ (table 3). Ozoga and Verme (1968) found this species

⁶ Haveman (1973) gives details of shrew distribution, food habits, and population in the McCormick Forest.

to be the most common small mammal in conifer swamps in the east-central Upper Peninsula (UP). Manville (1949) found masked shrew densities of 0.2 per acre in hemlock habitat and 4.2 per acre in a cedar swamp in the Huron Mountain area. Laundre (1974) in the same area found densities of 8.1 per acre in maples and 4.6 per acre in open meadows. It appears that shrew densities in the McCormick Forest were quite high in 1972.

Arctic shrew (Sorex arcticus).--Eight arctic shrews were captured, four each in the hardwood-pine and bog areas. Ozoga and Verme (1968) also caught this species in conifer swamps in the east-central UP. Neither Laundre (1974) nor Manville (1949) caught arctic shrews in their studies of mammals in the Huron Mountain area.

Water Shrew (Sorex palustris).--One water shrew was collected in a pitfall set for amphibians near Camp 11 Lake in July 1972. Another was seen on July 1, 1972, on the Yellow Dog River. This species is apparently not common anywhere (Burt 1948). Manville (1942) captured two water shrews in the Huron Mountain area, but Laundre (1974) caught none in that area. Ozoga and Verme (1968) likewise reported no captures of this species in their work in conifer swamps in Alger and Schoolcraft Counties.

Pigmy shrew (Microsorex hoyi).--Eleven pigmy shrews were captured during the study with population densities of up to only 3 per acre in the bog. None were caught in hardwood-pine habitat. Manville (1949) caught three pigmy shrews in the Huron Mountains but Laundre (1974) caught none. Ozoga and Verme (1968) captured none in the east-central UP. It appears that populations of pigmy shrews were unusually high on the McCormick

Table 3.--Shrew population densities on the McCormick Forest
(In number per acre¹)

Habitat	Year	<i>Sorex cinereus</i>	<i>Sorex arcticus</i>	<i>Microsorex hoyi</i>	<i>Blarina brevicauda</i>
Bog	1972	6	4	2	5
Bog	1973	5	0	3	3
Spruce swamp	1972	11	0	2	7
Spruce barrens	1972	4	0	1	1
Hardwood-pine	1972	9	4	0	19
Hardwood-pine	1973	4	0	0	7

¹Determined by trapping a 1-acre plot for 5 days. Only areas trapped one time are included because the high rate of removal probably influences subsequent estimates.

Forest as Burt (1948) noted only four records from the UP.

Short-tailed shrew (Blarina brevicauda).--

The short-tailed shrew was the most frequently captured shrew, with 48 being taken, and at least 1 from each habitat sampled. In 1972, 1 hardwood-pine plot had a density of at least 19 per acre. Manville (1949) found densities of up to 12 per acre in the Huron Mountain area, and Laundre (1974) found densities of up to 8 per acre. Highest densities were in the hardwood-pine area on the McCormick Forest, but other authors (Manville 1949, Ozoga and Verme 1968, Nofz 1972) report high densities from wetter areas. Apparently this abundant shrew has rather cosmopolitan habitat preferences.

Chiroptera

Little brown bat (Myotis lucifugus).--

The little brown bat was the only species of bat identified on the Forest. A colony of about 200 occupied the buildings near White Deer Lake. The colony was examined several times but no other species was found. The little brown bat is undoubtedly the most common bat in northern Michigan. Bats were not common on lakes other than White Deer and Bulldog.

Carnivora

Black bear (Euarctos = Ursus americanus).--

Tracks, droppings, and diggings of bears were found throughout the Forest. Two bears were seen in 1973, a yearling near Baraga Lakes and a large adult in the southwest corner of the Forest. The black bear is probably as abundant on the Forest as elsewhere in the UP. Because of the low level of human usage, however, the bears in the McCormick Forest are not prone to scavenging from human food supplies or refuse, and remain quite secretive.

*Raccoon (Procyon lotor).--*The raccoon has become common in the northern Upper Peninsula only in the past 25 years (DeVos 1964, Laundre 1974). Tracks were found along Lower Baraga Lake and along the east branch of the Yellow Dog River. A lactating female was observed closely with a spotlight from a canoe on Lower Baraga Lake on June 25, 1973. Raccoons seem to maintain low numbers in the McCormick Forest.

Weasels (Mustela erminea and M. frenata).--

The ermine (short-tailed weasel) and long-tailed weasel are combined in this discussion

because of the difficulty of distinguishing their tracks. Only one weasel, an ermine, was seen during the study. Tracks of 20 weasels were encountered during the winter indicating that they are widespread in the Forest but not abundant. Laundre (1974) collected a short-tailed weasel and the skull of a long-tailed weasel in the Huron Mountains in 1973. Manville (1942) collected six short-tailed and four long-tailed weasels in the Huron Mountain area.

*Fisher (Martes pennanti).--*The fisher was a former resident of Upper Michigan but was apparently trapped to extinction by the 1930's (Brander and Books 1973, Irvine *et al.* 1964, Manville 1942). Between 1961 and 1963, 61 fishers from Ontario were released in Iron County, about 90 miles southwest of the McCormick Forest. Continued collection of specimens indicates that the fisher has become re-established in Michigan (Brander and Books 1973). In the McCormick Forest five fisher tracks were found in the winter of 1972-73. Their location and travel routes indicated that there were probably no more than two present. Laundre (1974) found two sets of fisher tracks in the Huron Mountains in 1973-74. It appears that the fisher is present in low densities on the McCormick Forest.

*Mink (Mustela vison).--*Mink are common in the McCormick Forest although they are not frequently seen. On October 25, 1969, I saw one on the Peshekee River beneath the McCormick Road bridge. Seven mink tracks were found on March 20, 1973, and tracks were seen in the summer along the Peshekee River and Lower Baraga Lake. Laundre (1974) and Manville (1942) also found mink to be common in the Huron Mountains.

*Otter (Lutra canadensis).--*One otter was seen on a bog pond south of Lake Dortay. Scats were found at Lower Baraga and Island Lakes. In the winter eight otter tracks were found in various locations throughout the Forest. Similar low density but probably typical otter populations appear to exist in the Huron Mountains area (Laundre 1974).

*Red fox (Vulpes fulva).--*One fox was seen on the Forest and another about a mile south of it. Only four fox tracks were found during the winter. Manville (1942) reported foxes to be numerous in the Huron Mountain area, with 23 killed in 1932 and 1933. Laundre (1974) also regarded them as common there. The red fox appears to be uncommon on the McCormick Forest.

Coyote (Canis latrans).--One coyote was seen about 2 miles west of the Forest and one was heard howling in the southwest corner of the Forest. A few scats and tracks were found in the summer; 22 tracks were found during the winter. The coyote is uncommon, probably because it prefers open or semi-open country to heavily wooded terrain. Manville (1942) reported that the coyote was common in the Huron Mountain area but Laundre (1974) suggests it is uncommon there recently.

Wolf (Canis lupus).--It is estimated that only 6 to 10 native wolves remain in the Upper Peninsula after populations declined sharply in the late 1950's (Hendrickson *et al.* 1975). Four radio-tagged wolves were released in the Huron Mountains in March 1974 but none of these entered the McCormick Forest. In May 1972, tracks of a wolf were seen in the southwest part of the Forest. One was reported near Wolf Lake, about 5 miles southwest of the Forest in November of 1973. It can be concluded that the wolf is all but absent from the study area.

Bobcat (Lynx rufus).--Thirteen bobcat tracks were found during the winter and 3 in the summer. Laundre (1974) reported seeing a bobcat in the Huron Mountains and a few tracks. Manville (1942) reported the bobcat to be present but not abundant there. In the McCormick Forest bobcats seem to be somewhat more abundant than in the Huron Mountains, possibly because the snowshoe hare, its principal prey, is also more abundant.

Rodentia

Woodchuck (Marmota monax).--Nine sightings of woodchucks were made in the McCormick Forest. One was on the spruce barrens, another on the road, and the rest near the buildings at White Deer Lake; two sightings were in 1972, and seven in 1973. On County Road 607, south of the Forest, 4 sightings of woodchucks were made in 1972 and 19 in 1973. It is likely that the population increased in 1973. In the Huron Mountains both Manville (1942) and Laundre (1974) considered the woodchuck common. In the more continuous cover of the McCormick Forest it seems to be uncommon.

Least chipmunk (Eutamias minimus) and *Eastern chipmunk (Tamias striatus)*.--Both species of chipmunks are abundant in the Forest. Because of their abundance and conspicuous diurnal behavior, all sightings of chipmunks were not recorded. They were present in all habitats except the bog and there seemed to be little distinction between habitats of the two species.

More least chipmunks (33) than eastern chipmunks (29) were sighted on the Forest. On County Road 607, 46 sightings of least chipmunks were made to 31 of the eastern.

Laundre (1974) reported a decline in least chipmunks in the Huron Mountains between 1972 and 1973. No such decline appeared in the McCormick Forest with 16 recorded sightings in 1972 to 17 in 1973. (Sightings were recorded while we were walking but only on certain days.) Along County Road 607 in 1972, however, 27 sightings were made in 1972 to 19 in 1973, despite the fact that about 20 percent more miles were driven in 1973. Differences in population levels between the 2 years were not statistically significant.

Red squirrel (Tamiasciurus hudsonicus).--The red squirrel is common in the McCormick Forest; 29 were sighted during the study. During winter, 143 red squirrel tracks were found in 56 miles of hiking. Laundre (1974) recorded a sharp decline of this species in the Huron Mountain area between 1972 and 1973. No decrease in red squirrel numbers could be noted in the McCormick Forest with 11 sightings in 1972 and 18 in 1973. On County Road 607, however, eight squirrels were seen in 1972 and four in 1973. Laundre (1974) estimated a population of about 11 per acre in the Huron Mountains in summer of 1972 based on a call census. Although no quantitative data on density were gathered on the Forest, I estimate that there was less than one red squirrel per acre.

Northern flying squirrel (Glaucomys sabrinus).--Assessing the population of flying squirrels is difficult because of their secretive, nocturnal habits. During night lighting we saw one along the shore of White Deer Lake and one was heard along Bulldog Lake. Tracks of four flying squirrels were found in the snow at various locations, and it is possible that some tracks identified as red squirrel tracks could have been those of flying squirrels. Manville (1942) saw nine flying squirrels in 29 weeks in the Huron Mountain Club

⁷ By Donald Lappala, USDA Forest Service, Iron River.

between 1939 and 1942. Laundre (1974) saw only two in about 16 weeks in 1972 and 1973, about the same frequency as our two observations. The flying squirrel appears to be uncommon in the McCormick Forest.

Beaver (*Castor canadensis*).--The beaver is very common on the McCormick Forest. Night lighting produced 15 sightings, and 12 other beavers were seen in the daytime. Active colonies were present on practically every waterway and lake. At least 17 colonies with 9 known active lodges were present in 1973. Using Bradt's (1938) estimate of 2.4 beavers per colony with no lodge and 4.0 per colony with a lodge, at least 55 beavers were present. Using Manville's (1942) estimate of 5.1 beaver per colony a total of 87 beavers is obtained. Assuming that we may not have found several colonies, an estimate of a summer population of 70 to 100 beavers (2.6 to 3.8 per square mile) is probably realistic. This compares with 1.8 beavers per square mile in 1973 (Laundre 1974) and 4.7 per square mile in the early 1940's (Manville 1942) in the Huron Mountain area. Beaver trapping is permitted on the Forest but only one trapper was known to have trapped there. He caught an adult beaver in March 1972 on an un-named stream in Section 11.

Deer mouse (*Peromyscus maniculatus*).--Deer mice were abundant on the McCormick Forest; densities ranged up to 43 per acre in mature upland forest (table 4). Manville (1949) found somewhat lower densities than

this in the Huron Mountain area but Laundre (1974) found about 36 mice per acre in the mature maple forest there. By adjusting Manville's calculations to assume a somewhat smaller area of trap influence, Laundre concluded that Manville's deer mouse population densities were actually similar to his. Terman (1968) in reviewing literature, notes that populations greater than 11 per acre may be exceptionally high. It appears that deer mouse populations in the proper habitat in northern Michigan are very high relative to those in other areas.

Southern bog lemming (*Synaptomys cooperi*).We caught only three bog lemmings, one each in the bog, spruce-blueberry barrens, and the hardwood-pine forest. Both Manville (1942) and Laundre (1974) reported this species to be rare in the Huron Mountain area and that evaluation seems to apply in the McCormick Forest.

Boreal redback vole (*Clethrionomys gapperi*).--The redback vole is probably the second most common but the most widespread mouse in the McCormick Forest (table 4). It was found in all habitats sampled except the bog. Densities of six to eight voles per acre were estimated in the white birch-aspen and mature hardwood-white pine areas, consistent with densities in other areas (Laundre 1974, Jackson 1961, Manville 1949). Manville (1949) also found this species over a wide range of habitats in the Huron Mountains.

Meadow vole (*Microtus pennsylvanicus*).--Meadow voles were captured only in the bog

Table 4.--Estimated population densities of small rodents on the McCormick Forest (In animals per acre)

Habitat	Deer Mouse	Red-backed vole	Meadow mouse	Bog lemming
Hardwood-white ¹ pine, 1972	43 ²	8	0	2
Hardwood-white pine, 1973	19	6	0	0
White birch- aspen, 1972	5	6	0	0
Spruce-blueberry barrens, 1972	2	2	0	2
Spruce swamp, 1972	0	2	0	0
Bog, 1972	0	0	8	2

¹Estimates in this plot are based on a Lincoln Index (Giles 1969) of animals originally captured in live-traps and subsequently recaptured in pitfalls.

²Standard estimate against which catch per trap-night in live-traps or pitfalls in other habitats were compared.

habitat where six specimens were taken. This species prefers dense grassy cover (Jackson 1961) and sometimes reaches densities of up to 2,000 per acre (Aumann 1965). In the McCormick Forest populations are apparently scattered and not very dense where they do occur in grassy bogs and beaver meadows. Manville (1949) captured several meadow voles in bog and meadow habitats in the Huron Mountains but Laundre (1974) caught only one. Nofz (1972) likewise found low populations in the Keweenaw Peninsula, although it was present in a variety of habitats, and Ozoga and Verme (1968) found small numbers of meadow voles in conifer swamps in Alger and Schoolcraft Counties. Investigators in Upper Michigan have not reported more than 10 voles per acre; thus it appears that meadow voles do not reach high densities in this area.

Muskrat (Ondatra zibethica).--Probably all the lakes and streams in the McCormick Forest support muskrats. Nowhere are they abundant, however, probably because there are no extensive marshes or shallows with rich emergent vegetation that muskrats thrive on. Tracks, droppings, or muskrats themselves were seen on Bulldog, White Deer, Round, Margaret, Groves, Island, and Baraga Lakes. Laundre (1974) and Manville (1942) both concluded that the muskrat is common in the Huron Mountains but not abundant. The same can be said for the McCormick Forest.

Meadow jumping mouse (Zapus hudsonius) and woodland jumping mouse (Napeozapus insignis).--Five meadow jumping mice were found during the study. Two were trapped in pitfalls in the hardwood-white pine area, one was trapped in live-traps in the birch-aspen area, and two juveniles were caught by hand near Lower Baraga Lake. A jumping mouse of undetermined species was seen near Groves Lake, and a woodland jumping mouse, identifiable by its white-tipped tail, was seen near Summit Lake. Densities of both species are probably less than one mouse per acre. Manville (1949) and Laundre (1974) also found low densities of jumping mice in the Huron Mountain area and Ozoga and Verme (1968) found very low populations of both species in swamps in east-central Upper Michigan. Nofz (1972) found similar low densities of woodland jumping mice in the Keweenaw Peninsula but somewhat higher densities of meadow jumping mice. Although he gave no estimate of population density, Nofz' catch per unit effort and relative density (15 percent of the small mammals

captured in swamp habitats) indicate populations several times denser than those in northern Marquette County and east-central Upper Michigan. Such differences, however, could be accounted for by annual variations in numbers.

Porcupine (Erethizon dorsatum).--Casual observations indicate that porcupines in northwestern Marquette County have declined in the past 20 years and are no longer common. In the McCormick Forest only three porcupines were seen in the 2 years of this study. Although hemlock groves were searched carefully in the winter, no signs of porcupine could be found, and not a single track was seen in 69 miles of walking. Manville (1942) saw 20 porcupines in 31 days afield in summer of 1942 in the Huron Mountains, and in 1939, 36 porcupines were killed along Cedar Creek near the Huron Mountains. Laundre (1974) found porcupine populations to be sparse in the Huron Mountains. Whether or not the decline in porcupines is related to the re-establishment of the fisher, which preys upon them, can only be speculated.

Lagomorpha

Snowshoe hare (Lepus americanus).--Snowshoe hares were abundant on the McCormick Forest. Fifteen animals were seen, and their tracks could be found in winter in nearly all areas where coniferous trees were growing. A winter track count kept during 51 miles of walking in a typical assortment of habitats yielded an index of 1.0 snowshoe hare tracks per-10-miles per-hour-since-snowfall. On January 30, 1973, a walk of 5.5 miles in good snowshoe hare habitat along the south border of the Forest crossed 308 hare tracks laid down in the previous 48 hours for an index of 11.3 tracks per-10-miles per-hour-since-snowfall. On May 17, 1973, an observer⁸ saw five hares together within 20 feet of him near the bridge on the McCormick Road. Snowshoe hares are considerably more abundant on the McCormick Forest than in the Huron Mountains (Laundre 1974). Hares are subject to great fluctuations in populations (Keith 1963). To what extent their density in the McCormick Forest is temporary cannot be determined without long-term observations.

Artiodactyla

White-tailed deer (Odocoileus virginianus).--Deer are common in the McCormick Forest from May through November. They apparently winter near

⁸ James Haveman.

Lake Superior 8 to 18 miles to the north, possibly in the Huron Mountain area (Westover 1971). During the winter of 1972-73 the last deer track on the McCormick Forest was found on January 23 and the first returning tracks were seen on April 24. On that date tracks of about 30 deer were seen along Baraga Lakes trail and crossing the McCormick Road. About 95 percent of these were headed south, probably migrating from winter yards in the north.

We saw 44 deer during 72 trips to the study area, an average of 0.61 deer per trip. These 44 deer were in 31 groups of 1 to 4 animals, so the probability of seeing a deer on a trip to the study area was 0.43. On County Road 607 between highway U.S. 41 and the McCormick Forest, nine deer were seen.

In the 1972 deer-hunting season an 8-point buck was shot on opening day in the southwest part of the Forest and several bucks were reportedly taken along the northern boundary (Robinson 1973). Ryel *et al.* (1972) estimated, on the basis of pellet counts, an average of about six deer per square mile in the Lake Superior Watershed in 1972. Laundre (1974) made extensive pellet counts in the Huron Mountains in the spring of 1974 and estimated a deer population there of 74 deer per square mile in the winter yard. Because of relatively mild winters since 1969, the deer population appears to be increasing somewhat.

Man (Homo sapiens).--Although evidence of man's former presence in the McCormick Forest is abundant in the form of old roads, dams, and cut stumps, people were encountered less frequently than deer and beaver. Since 1970 it has been illegal to drive any wheeled vehicle past the gate off County Road 607, and overnight camping has been prohibited. In 28 trips in 1972, 9 automobiles other than our own were seen parked at the gate and in 1973 only 4 were seen there in 44 trips. A total of 15 visitors, excluding research and management personnel, were encountered during the 2 summers. Only three instances of illegal overnight camping were found. On November 15, 1972, the opening of deer-hunting season, six people legally camped at the gate. Human use may be more frequent in winter. On the weekend of February 24, 1973, an observer reported that 24 people in small groups had snowshoed and skied to and from the lodge at White Deer Lake.

On summer nights all sounds of human origin other than our own were noted. In

21 hours of listening and canoeing only three airplanes and two trucks could be heard for an average of less than one machine sound per 4 hours. On July 28, 1972, and January 3, 1973, when the air was somewhat stagnant, the odor of iron ore pelletizing was noted. The source was probably the operations at Humboldt or Republic 12 to 18 miles to the southeast.

Other Mammals Possibly Present

Some species of mammals besides those discussed may be present on the McCormick Forest because they are present in the Upper Peninsula, but for various reasons were not seen or identified on the study area.

Opossum (Didelphis marsupialis).--This mammal is extending its range northward. Only two reports are known from the UP, one from Iron County, 60 miles southwest of the McCormick Forest, and one from Gogebic County, 100 miles southwest (Ozoga and Gaertner 1963). The opossum is probably not present on the McCormick Forest.

Star-nosed mole (Condylura cristata).--This mole is found in the Huron Mountain Club (six specimens, Laundre 1974); 9 miles northeast of McCormick Forest, and is probably present in the McCormick Forest.

Keen bat (Myotis keenii).--Specimens of this uncommon bat have been collected from Baraga and Marquette Counties according to University of Michigan Museum of Zoology Records and in the Keweenaw Peninsula (Stones and Fritz 1969). It is probably present on the McCormick Forest.

Silver-haired bat (Lasionycteris noctivagans).--Manville (1942) reported seeing a silver-haired bat in the Huron Mountain Club although Laundre (1974) found none in that area. Stones and Holyoak (1970) collected one in 1970 in northern Houghton County. It may be present but rare in the McCormick Forest.

Big-brown bat (Eptesicus fuscus).--This bat was seen by Manville (1942) but not by Laundre (1974) in the Huron Mountain Club. Stones and Fritz (1969) found this species in mines in the Keweenaw Peninsula. It is probably present in the McCormick Forest.

Red bat (Lasiurus borealis).--It is likely that this species is present on the

McCormick Forest although neither Manville (1942) nor Laundre (1974) found it on the Huron Mountain Club. The University of Michigan Museum has specimens from Chippewa and Gogebic Counties. Nichols and Stones (1971) reported it on Isle Royale.

Hoary bat (Lasiurus cinereus).--Neither Manville (1942) nor Laundre (1974) found this bat in the Huron Mountain area. Specimens in the University of Michigan Museum include one from Gogebic County (1920) and two from Keweenaw County (1948). Its status in the McCormick Forest is unknown.

Marten (Martes americana).--The marten is extinct from about 1920 until 99 were released in 1969 and 1970 about 60 miles southeast of McCormick Forest. Laundre (1974) saw one on Huron Mountain Club in July 1973 10 miles north of McCormick Forest, but no other nearby reports of specimens have been made.

Striped skunk (Mephitis mephitis).--This animal is common near civilized and agricultural areas of the UP. There may be only an occasional individual in the McCormick Forest.

Badger (Taxidea taxus).--The badger is rare in most of the UP. Manville (1942) reported signs of one in Huron Mountains and Long (1972) examined a specimen collected near Sands in central Marquette County. It is probably not present in the McCormick Forest.

Gray fox (Urocyon cinereoargenteus).--Laundre (1974) reported seeing a gray fox in the Huron Mountain Club and several specimens have been taken from Central UP (Ozoga and Perme 1966). An occasional individual may be present.

Lynx (Lynx canadensis).--Harger (1965) reports possible resurgence of this species in the UP with 12 specimens taken in 1962. A lynx was killed near Negaunee in June 1972, 10 miles east of the McCormick Forest. Occasional individuals may be present.

Domestic cat (Felis domesticus).--Laundre (1974) reported seeing a feral house cat in the Huron Mountain area and a emaciated cat was found on the Yellow Dog Plains, 3 miles north of the McCormick Forest in fall of 1972.⁹ It is not likely that the domestic cat could survive in the McCormick Forest.

Thirteen-lined ground squirrel (Spermophilus tridecemlineatus).--One was

captured by us by hand 8 miles south of the McCormick Forest in July 1972. Has also been reported from Big Bay and the Huron Mountain area (Phillips and Robinson 1969, Laundre 1974). Because of lack of grassland habitat it is probably absent from the McCormick Forest.

Gray squirrel (Sciurus carolinensis).--The reason for the absence of this species in the McCormick Forest is a mystery. None were seen and no nests, gnawings, or tracks were found despite careful search and the presence of several large mature oak stands and good acorn crops. I have seen gray squirrels near Big Bay, and on the Yellow Dog Plains, 5 miles northeast of the McCormick Forest (October 1973) along U.S. 41, 7 miles south of the McCormick Forest, and near Skanee, 12 miles northwest of the McCormick Forest. Nofz (1972) reported them from Keweenaw County. Because the gray squirrel has been slowly spreading its range northward, it is possible that all gaps in its range have not been filled in yet and the McCormick Forest may be one such gap.

Southern flying squirrel (Glaucomys volans).--Two specimens were recently captured by James Haveman in central Marquette County, the farthest north this species has been reported.¹⁰ It is not likely that it has reached the McCormick Forest.

Norway rat (Rattus norvegicus).--Manville (1942) reported the rat at the Huron Mountain Club prior to 1906 and Laundre (1974) mentioned possible rats there in the late 1960's, but none in the early 1970's. Nofz (1972) reported this species in wild lands in the Keweenaw Peninsula. It can be found in cities in the UP. It is unlikely, however, that rats occur on the McCormick Forest.

House mouse (Mus musculus).--Manville (1942) captured four house mice in the Huron Mountain area but Laundre (1974) found no evidence of them there in the early 1970's. It is probably absent on the McCormick Forest.

Cottontail rabbit (Sylvilagus floridanus).--In northern Upper Michigan the cottontail is associated only with civilization. Isolated populations exist in the cities with practically no rabbits found in wooded areas between.

¹⁰ J. Haveman and W. L. Robinson. Occurrence of the southern flying squirrel in Upper Michigan. Jack Pine Warbler. (In press.)

⁹ By Fred Rydholm, 1973.

No evidence of cottontails was found in the McCormick Forest and it is unlikely that they are present there. Manville (1942) reported them in the Huron Mountain Club but Laundre (1974) reported only possible recent sightings and believes the cottontail to be absent from that area as well.

Moose (Alces alces).--No sign of moose was found during this study. This animal formerly ranged throughout the UP. It is still present in low numbers. In the winter of 1968-69 tracks and droppings of a moose were found on the Yellow Dog Plains about 3 miles northeast of the McCormick Forest. In May 1972 a 3-year-old bull was found dead 8 miles west of the McCormick Forest and autopsied by Department of Natural Resources biologists. In July 1973 a cow was seen by a DNR employee near Craig Lake about 7 miles west of the study area. It is likely that an occasional moose wanders through the McCormick Forest.

It is likely that the present populations of birds and mammals of the McCormick Forest are similar to those found throughout most of the 1,000-square-mile area that lies north of U.S. Highway 41 between Marquette and L'Anse. Future changes may occur, however, as the human population expands, and invasion of wild areas by people increases. Natural succession may also play a role in changing the biological communities present. Future studies may reveal the nature and extent of these changes.

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AMPHIBIANS AND REPTILES

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ABSTRACT.--During the spring and summer of 1972 and 1973, a herpetological survey was conducted in the Cyrus H. McCormick Experimental Forest in Marquette and Baraga Counties, Michigan. Eleven amphibian and 5 reptile species were found. The 16 species represent 62 percent of the known herptofauna of the area. During the summer of 1973 population estimates were made on common amphibians that inhabited a bog, stream, woods, and marsh-pond habitat. The estimates were converted to biomass per hectare. About twice as much amphibian biomass was found in the bog (43,257 grams) as in the pond (26,323 grams) and three and a half times as much in the bog as in the stream (12,164 grams). The hardwoods were the least productive accounting for 730 grams per hectare.

Amphibians and reptiles are among the least known, the least studied, and the least abundant vertebrate fauna of the Upper Peninsula of Michigan. Since the early surveys of Ruthven *et al.* (1928), fewer than six published articles have dealt exclusively with Upper Peninsula herptofauna. Only two references (Manville 1948, Johnson¹), include locality records in the vicinity of the McCormick Forest in western Marquette and eastern Baraga Counties. These authors list 16 species of amphibians and 10 species of reptiles for the central Upper Peninsula in which the McCormick Forest is located. Range maps by Conant (1958) indicate that about half of these species extend no further north than Lake Superior, just 15 miles from the McCormick Forest.

During 1972-73, a herpetological survey was undertaken as part of a general inventory of vertebrate fauna of the McCormick Forest (Werner 1973, Robinson 1973). Because the forest had not been previously surveyed, new locality records were established for all species found and information was collected on the distribution and abundance of each species. In 1973, the studies were expanded to estimate

population densities and standing crop figures for the common amphibian species.

MATERIALS AND METHODS

During the spring and summer of 1972 and 1973, my student assistants and I surveyed the Forest (described by Robinson, Part I, this report) on foot or by canoe. Amphibians and reptiles were captured by various techniques including open pitfalls, minnow traps, seines dip nets, and hand.

From early May through June of 1973, four areas were selected for intensive study based on the presence of known populations. The four areas are as follows. (1.) The bog site (NW $\frac{1}{4}$ of NW $\frac{1}{4}$, Sec 11, T49N, R30W; fig. 1) consisted of 0.18 hectare of northern bog. About two-thirds of the area was covered by 15 to 30 cm of standing water; the remaining area was matted with *Sphagnum* moss, pitcher plants (*Sarracenia purpurea*), sweet gale (*Myrica gale*), leatherleaf (*Chamaedaphne calyculata*), cranberry (*Vaccinium* sp.), and other bog plants. The site was bounded on the east by a high rock ledge and on two sides by stands of tamarack (*Larix laricina*), tag alder (*Alnus rugosa*), and leatherleaf. The northern end was open to a larger bog area.

(2.) The pond site (SE $\frac{1}{4}$ of NE $\frac{1}{4}$, Sec 10, T49N, R30W; fig. 1) consisted of 0.21 hectare of pond-marsh habitat in which various

¹Wendel John Wagner Johnson. A Zoogeographical analysis of the herptofauna in northern Michigan and adjacent Isle Royale. 90 p. Unpublished M.S. Thesis, Mich. State Univ. 1965.

unidentified grasses and sedges predominated although a few bog plants such as leatherleaf and sweet gale were also present. At the beginning of the study period, about half of the area was under 8 to 46 cm of water which receded to cover less than one-eighth of the area at the end of the period. The site was bounded on all four sides by steep rock cliffs or forested hills, except where a stream entered and departed through narrow gaps in the rock.

(3.) The stream site (SE $\frac{1}{4}$ of NW $\frac{1}{4}$, Sec 10, T49N, R30W; fig. 1) consisted of 95 m of stream, which varied from 0.61 to 1.83 m in width and from 5 to 46 cm in depth. Gravel and scattered boulders lined the streambed except for back eddies of loose silt. The water was generally fast moving, dropping about 6 m in the 95 m of stream. The grid site extended into the forest 3 m on each side, thus, the stream grid encompassed 0.11 hectares.

(4.) The woods site incorporated three separate plots in mixed hardwoods. The dominant canopy trees in one plot (NW $\frac{1}{4}$ of NW $\frac{1}{4}$, Sec 11, T49N, R30W; fig. 1) were white pine (*Pinus strobus*) and hemlock (*Tsuga canadensis*). In the second and third plots (SE $\frac{1}{4}$ of NE $\frac{1}{4}$, Sec 30, T50N, R29W) sugar maple (*Acer saccharum*) and yellow birch (*Betula alleghaniensis*) predominated.

The bog, pond, and stream sites were gridded into 10-by 10-ft (3.03-by 3.03-m) plots using 12-gauge wire and small colored plastic markers. The grids were sampled a minimum of six times at about 3-day intervals (2 to 4 days). During each sampling period, two groups of students of three to four individuals each, spent about 3 hours carefully searching the entire grid in an orderly sequence. All animals captured (either by hand or nets) were toe-clipped, measured (body length, head width), sexed (when possible), and released. About 75 percent of the sampling was done at night using headlamps. Populations were estimated by the Schumacher method (DeLury 1958) or as otherwise indicated.

The only amphibian found with regularity in the hardwood areas was the red-backed salamander (*Plethodon cinereus*). Because mark and recapture techniques are not successful with this amphibian, two alternative methods of sampling were used and the results averaged. In the first method (Heatwole 1962) a total of 30

square-meter plots was layed out at 10-meter intervals on a fixed grid and analyzed layer by layer down to and including the A₂ soil horizon. The second method, referred to as the suitable habitat method, was based on the assumption that the majority of individuals in any one area are found in or under decaying logs. The assumption was based on extensive field work in the area and supported by Heatwole for northern hardwood regions.

In the suitable habitat method, 1 square meter of log (diameter x appropriate length) from each of 10 randomly selected logs in the grid was examined carefully piece by piece and a frequency index established based on the average number of salamanders per volume of log. The volume of the log rather than its area was chosen for final analysis because it was more indicative of the amount of habitat examined. To calculate volume, the diameter and length measurements of the square meter were considered as delineating a cylinder whose volume was determined by the formula $\pi r^2 h$, where r is the radius and h the length. Following establishment of a frequency index, a straight line of 91 m (300 feet) was then laid out by compass through the grid and the number and volume of suitable logs 1 m on each side of the line was recorded. From the total area canvassed and the frequency index, the total number of salamanders per hectare was estimated.

Biomass figures were derived by constructing a weight-length curve for each species from measurements made in the field on 10 to 50 live individuals. The values were converted to log values and plotted on graph paper, yielding approximate straight lines, whose equations were determined by the method of least squares (table 1). The equations were used to convert all individual measurements to biomass.

RESULTS

Survey

The species encountered, their density index, general habitat types, and locality records are summarized in table 2. Two snakes (ring-necked (*Diadophis punctatus*), and red-bellied (*Storeria occipitomaculata*)), and one salamander, the four-toed salamander (*Hemidactylium scutatum*), were found only once and are considered rare.

Table 1.--Regression equations of body weight (y) on body length (x) for amphibian species found in the McCormick Forest.

Species	N	Equation
<i>R. catesbiana</i>	13	$\log Y_e = -4.149 + 2.89 \log x$
<i>R. clamitans</i>	58	$\log Y_e = -4.147 + 2.88 \log x$
<i>R. septentrionalis</i>	36	$\log Y_e = -5.339 + 3.20 \log x$
<i>R. pipiens</i>	34	$\log Y_e = -4.150 + 2.84 \log x$
<i>R. sylvatica</i>	27	$\log Y_e = -4.637 + 2.52 \log x$
<i>H. crucifer</i>	26	$\log Y_e = -4.485 + 2.41 \log x$
<i>B. americanus</i>	35	$\log Y_e = -5.854 + 3.07 \log x$
<i>P. cinereus</i>	44	$\log Y_e = -4.201 + 2.58 \log x$

Table 2.--Summary of amphibian and reptile survey of the McCormick Forest, 1972-73.

Species	Frequency index ¹	Habitat	Number of section where found ²
Caudata			
<i>Plethodon cinereus</i> (Red-backed salamander)	Common	Wooded uplands	1, 2, 3, <u>10</u> , 19, 22, 23, <u>30</u> , 32
<i>Hemidactylium scutatum</i> (Four-toed salamander)	Rare	Bog	<u>15</u>
<i>Ambystoma laterale</i> (Blue-spotted salamander)	Few	Ponds, bog, marsh	2, 3, <u>11</u> , 22, <u>32</u>
<i>Notophthalmus viridescens</i> (Central newt)	Few	Lakes	3, <u>11</u> , <u>31</u> , <u>35</u>
Anura			
<i>Bufo americanus</i> (American toad)	Common	Wooded uplands, lakes, marshes, ponds, bogs, streams	1, 2, 3, 7, <u>10</u> , <u>11</u> , <u>12</u> , 22, 23, 26, 34
<i>Rana clamitans</i> (Green frog)	Common	Lakes, ponds, marsh, bogs, streams	1, 2, 3, 7, <u>10</u> , <u>11</u> , <u>12</u> , 22, 23, 27, 32, 34, 35, 36
<i>Rana pipiens</i> (Leopard frog)	Common	Lakes, marsh, ponds, bogs	1, 2, 3, 7, <u>10</u> , <u>11</u> , 12, 19, 22, 26, 27, 35
<i>Rana catesbiana</i> (Bullfrog)	Frequent	Lakes, bogs, marsh	1, 3, <u>10</u> , <u>11</u> , 35
<i>Rana sylvatica</i> (Wood frog)	Frequent	Wooded uplands, streams, ponds, bogs, marsh	2, 3, <u>10</u> , <u>11</u> , 19, 23, 23, <u>30</u> , <u>32</u> , 35
<i>Rana septentrionalis</i> (Mink frog)	Frequent	Lakes, bog, marsh, pond	1, <u>10</u> , <u>11</u> , 35
<i>Hyla crucifer</i> (Spring peeper)	Frequent	Lakes, bog, marsh, pond, stream, wooded uplands	3, <u>10</u> , <u>11</u> , <u>32</u> , <u>34</u> , <u>35</u>
Chelonia			
<i>Chrysemys picta</i> (Painted turtle)	Few	Ponds, lakes	<u>1</u>
<i>Chelydra serpentina</i> (Snapping turtle)	Few	Lakes, ponds, marshes	<u>1</u> , 3, 26
Serpentes			
<i>Thamnophis sirtalis</i> (Eastern garter snake)	Frequent	Lakes, ponds, marshes	1, 3, <u>10</u> , 15
<i>Storeria occipitomaculata</i> (Red-bellied snake)	Rare	Wooded uplands	<u>15</u>
<i>Diadophis punctatus</i> (Ring-necked snake)	Rare	Wooded uplands	<u>10</u>

¹Rare--seen less than 25 percent of the time (less than one sighting for every four trips); few--seen at least 25 percent of the time; frequent--seen at least 50 percent of the time; common--seen 100 percent of the time.

²See location of sections on figure 1. Underlined numbers indicate that the specimens were collected there. Nonunderlined numbers indicate that the animal was sighted only.

Most of the frog species were commonly found during the spring-early summer breeding season but tended to become scarce as the season progressed. The exceptions were the leopard frog (*Rana pipiens*), green frog (*Rana clamitans*), and American toad (*Bufo americanus*), which were common throughout most of the summer.

Among Urodeles, the red-backed salamander (*Plethodon cinereus*) and the blue-spotted salamander (*Ambystoma laterale*) were found in forested areas, the former commonly, the latter uncommonly near ponds, bogs, or lakes. Central newts (*Notophthalmus viridescens*) were found together throughout the summer in localities such as Baraga Lake, Bulldog Lake, Clear Lake, and Two-Hole Bog.

Only a few painted turtles (*Chrysemys picta*) and snappers (*Chelydra serpentina*) were found. Female painted turtles were found laying eggs near the shore of White Deer Lake in June of 1972 and 1973.

The garter snake (*Thamnophis sirtalis*) was common in most aquatic habitats especially during the spring-early summer when its amphibian prey was abundant.

Five additional species, the spotted salamander (*Ambystoma maculatum*), the gray treefrog (*Hyla versicolor*), the pickerel frog (*Rana paulustris*), the Blandings turtle (*Emydoidea blandingi*), and the fox or pine snake (*Elaphe vulpina*), probably

inhabit the Forest based on locality records by Manville (1948) and Johnson¹, but were not found. The gray treefrog was collected 2½ miles south of the Forest on June 20, 1974, and the Blanding's turtle has been seen in the past, several miles north of the Forest².

Population Studies

The total number of marked and recaptured animals in all samplings is summarized in table 3. With the exception of the American toad and the spring peeper, the third or fourth sampling usually resulted in recapture success of 50 percent or better allowing for reasonable estimates and confidence limits (table 4).

Population estimates of the spring peeper and the American toad were complicated by the fact that the sampling period spanned the end of the breeding period of both species in the bog, hence emigrating animals were counted. The sampling also spanned the metamorphosing period of toads in the pond causing new additions to the pond population to be counted. A significant emigration and immigration rate or both violated the assumption of a constant population level during sampling, which is necessary for multiple mark-recapture methods, including the Schumacher. Thus the population estimates for both species are subject to error.

²By Fred Rydholm, a native of the area.

Table 3.--Mark-recapture data on seven amphibian species found in the McCormick Forest

Date (all during 1973)	Bog				Pond				Stream			
	<i>R. catesbeiana</i>	<i>R. clamitans</i>	<i>B. americanus</i>	<i>H. crucifer</i>	<i>R. pipiens</i>	<i>R. septentrionalis</i>	<i>R. clamitans</i>	<i>B. americanus</i>	<i>H. crucifer</i>	<i>R. sylvatica</i>	<i>R. clamitans</i>	<i>B. americanus</i>
May 27	--	0/13 ¹	0/17	0/29	--	--	--	--	--	--	--	--
May 28	--	--	--	--	0/9	0/18	0/38	0/1	0/28	--	--	--
May 29	--	--	--	--	--	--	--	--	--	0/4	0/5	0/3
May 30	0/4	5/20	10/60	7/43	--	--	--	--	--	--	--	--
May 31	--	--	--	--	0/5	2/5	13/24	0/6	1/30	--	--	--
June 1	--	--	--	--	--	--	--	--	--	5/10	1/2	0/10
June 3	4/5	9/27	3/8	13/43	2/6	4/8	16/21	1/34	1/14	--	--	--
June 4	--	--	--	--	--	--	--	--	--	1/3	0/3	1/11
June 6	3/3	21/44	4/4	1/2	--	--	--	--	--	4/5	1/3	2/29
June 7	--	--	--	--	5/10	5/11	22/30	5/65	4/7	--	--	--
June 8	--	--	--	--	--	--	--	--	--	4/5	2/2	8/25
June 9	2/7	21/42	--	--	--	--	--	--	--	--	--	--
June 11	--	--	--	--	9/11	3/3	18/22	19/44	1/4	1/4	1/3	7/12
June 12	4/4	15/20	--	--	--	--	--	--	--	--	--	--
June 13	--	--	--	--	--	--	--	--	--	5/10	1/3	10/13
June 14	--	--	--	--	3/3	4/5	16/21	20/73	2/10	--	--	--
June 16	4/4	--	--	--	--	--	--	--	--	2/3	7/9	9/10
June 18	--	--	--	--	--	--	--	--	--	5/6	2/4	4/5

¹ First number indicates the number marked in the sample, the second number sample size.

Table 4.--Estimated population of amphibians in four habitats
(In number per hectare)

Species	Bog	Pond	Stream	Woods
<i>R. catesbiana</i>	51 (34-89) ¹	--	--	--
<i>R. clamitans</i>	657 (516-898)	358 (316-411)	197 (144-251)	--
<i>R. septentrionalis</i>	39	206 (158-282)	--	--
<i>R. pipiens</i>	78	148 (114-200)	--	--
<i>R. sylvatica</i>	--	38	206 (152-314)	--
<i>H. crucifer</i>	1157 (943-1,494)	1,478	27	--
<i>B. americanus</i>	629	1,751	968 (780-1,282)	--
<i>P. cinereus</i>	--	--	--	838

¹Figures in parenthesis are 95 percent confidence limits (0.05).

In the bog, the leopard frog (*R. pipiens*) and the mink frog (*R. septentrionalis*) were found only occasionally within the grid. Population estimates of these two species based on mark-recapture were not possible because of the small number captured; instead the population was estimated to be the total number found during all samplings. The same situation prevailed with respect to the woodfrog (*R. sylvatica*) in the pond.

Bog

Between May 27 and June 3, 1973, the bog habitat was dominated by three species; the spring peeper, (1,157 individuals per hectare), the American toad (629 individuals per hectare) and the green frog, (657 individuals per hectare) (table 4). After June,

the former two species disappeared from the grid and bullfrogs increased in number.

A total of 10 bullfrogs (*R. catesbiana*) were marked of which eight were recaptured. Bullfrogs constituted 16 percent of the total amphibian biomass (table 5), although their number was only 2 percent of the total--a reflection of their larger size and weight.

The green frog (*R. clamitans*) far outnumbered other *Rana* spp., not only in the bog, but in most other areas. A total of 90 individuals were marked, of which 26 were captured once, 16 captured twice, and 3 captured 3 or more times, yielding a population estimate of 657 per hectare. The biomass contribution of the green frog was 18,938 grams per hectare, 44 percent of the total.

Table 5.--Amphibian biomass from four habitats
(In grams per hectare)

Species	Bog	Pond	Stream	Woods
<i>R. catesbiana</i>	6,956 (16) ¹	--	--	--
<i>R. clamitans</i>	18,938 (44)	7,797 (29)	3,312 (27)	--
<i>R. septentrionalis</i>	504 (1)	2,045 (8)	--	--
<i>R. pipiens</i>	772 (2)	1,860 (7)	--	--
<i>R. sylvatica</i>	--	229 (1)	1,570 (13)	--
<i>H. crucifer</i>	2,125 (5)	2,315 (9)	15 (1)	--
<i>B. americanus</i>	13,962 (32)	12,076 (46)	7,267 (60)	--
<i>P. cinereus</i>	--	--	--	730 (100)
Total	43,257	26,323	12,164	730

¹Figures in parenthesis are percent of total biomass.

A total of 14 leopard frogs and 7 mink frogs were captured in the bog grid; together they made up 3 percent of the total biomass.

Pond

The pond habitat differed from the bog in the absence of the bullfrog and the increase in mink and leopard frogs. A total of 25 leopard frogs were marked, 13 of which were later recaptured. Of the more secretive mink frogs, 32 were marked, of which 10 were recaptured. The biomass contribution of both species was nearly identical (7 and 8 percent), although their population densities were different; 206 per hectare and 148 per hectare for the mink and leopard frogs, respectively. Dole (1965) found 311 leopard frogs per hectare in a comparative study in Michigan's Lower Peninsula.

The two most common amphibians of the pond were the spring peeper and the American toad. Unlike those in the bog, however, toad populations in the pond consisted primarily of young juveniles and recent hatchlings. In fact, only 25 percent (19 of 77) of the individuals in the pond were adults, whereas in the bog all of the population were adults (50 mm or greater snout-vent length). The difference in age also reflects on the biomass, i.e., the population density in the pond was almost three times that of the bog, but the biomass was actually less. The fact that the spring peeper had the second highest population estimate in the pond (1,478 per hectare), yet contributed only 9 percent of the total biomass, is because of its small size.

The predominant ranid in the pond was again the green frog; 66 were marked and 40 were recaptured, yielding 358 individuals per hectare. Martof (1956) in a study of green frog populations near Ann Arbor, Michigan, reported 229 individuals per hectare during a comparable sampling period. Eight wood frogs were captured at the west end of the pond near the stream and are thought to have been the remnants of a breeding congregation. They contributed 1 percent of the total biomass (229 grams per hectare).

Stream

In the stream habitat, green and wood frogs were about equal in number (200 individuals per hectare). However, the biomass contribution of the green frog was more than twice that of the wood frog (29 percent and 12 percent, respectively). The green frog population along the stream was much smaller

than the 467 per hectare stream population studied by Martof in the Ann Arbor region. At no time were other ranid species encountered along the stream, although a few spring peepers were captured on two occasions.

The toad population along the stream was about half adults and half juveniles. The population estimate of 968 individuals per hectare far outnumbered that of other amphibians.

Woods

In the hardwood forests, the red-backed salamander (*Plethodon cinereus*) was the only amphibian found in measurable quantities although a few adult and juvenile toads as well as one blue-spotted salamander (*Ambystoma laterale*) were found in site No. 1. The two different methods of estimating *P. cinereus* population produced similar results. In site No. 1, the quadrat method yielded 665 individuals per hectare, the suitable habitat method, 549 per hectare; in site No. 2, the estimates were 333 and 355 individuals per hectare; and in site No. 3, which was notably more populated, the quadrat method yielded 1,334 individuals per hectare, and the suitable habitat method 1,792 individuals per hectare. The data averaged 838 individuals per hectare for all areas and all methods and amounted to 730 grams of biomass per hectare. The range of population estimates for the red-backed salamander (333 to 1792 individuals per hectare) compares with 90 to 1000 individuals per hectare found by Heatwole (1962) in several wooded habitats in lower Michigan. Both of these studies indicate that population densities of the red-backed salamander are quite variable from locality to locality.

DISCUSSION

The Schumacher method assumes that the population level remains constant throughout the sampling period, i.e., that dilution and mortality are negligible. In this study, even though the sampling period was short (2½ weeks), it is unreasonable to assume that there wasn't some dilution, mortality, or both. The question is whether it was significant enough to invalidate the results.

Two statistical tests were made to help assess the constancy of the population level. Leslie Method C (1952) indicated no significant dilution (table 6). Mortality coefficients (DeLury 1958) were calculated (assuming no dilution) even though a constant interval between sampling periods was not

Table 6.--Chi-square test for dilution¹ in five ranid populations in three habitats

Species	Value	Bog	Pond	Stream
<i>R. catesbiana</i>	χ^2	10.27(10) ^{3/}	--	--
	μ^2	-0.152	--	--
<i>R. clamitans</i>	χ^2	14.17(10)	14.07(10)	17.53(28)
	μ	-0.178	-0.234	-0.017
<i>R. septentrionalis</i>	χ^2	--	4.08(10)	--
	μ	--	0.424	--
<i>R. pipiens</i>	χ^2	--	8.12(10)	--
	μ	--	0.386	--
<i>R. sylvatica</i>	χ^2	--	--	33.61(28)
	μ	--	--	-0.141

^{1/} Leslie (1952).

^{2/} Mortality coefficient (DeLury 1958).

^{3/} Figures in parenthesis are degrees of freedom.

strictly adhered to. (The interval between samplings ranged from 2 to 4 days (table 2) averaging about 3 days.) The coefficients were either negative or unreasonably large (table 6) indicating that mortality was probably not a factor in explaining the present results. These tests were not made on the toad and spring peeper populations because, as previously pointed out, substantial immigration and emigration was known to have occurred.

Several apparent differences between populations were evident: both the American toad and spring peeper bred earlier in the pond than in the bog. This is possibly due to the 2 to 3° C lower water temperature recorded during each sampling period in the bog. A second difference between bog and pond populations of the American toad was that after breeding no adult toads could be found in the bog, but some adults were always present in the pond. The pond area, however, tended to dry up as the sampling period ended, creating more terrestrial conditions, perhaps encouraging adults to remain in the area. It did not appear that any toads of the stream population were breeding. No eggs, tadpoles, or adults in amplexus were found. Most likely, toads found along the stream had either bred earlier in nearby ponds or did not breed at all.

The population data correlated with those of the general survey of the Forest, in which numerous bogs, marshes, streams, and lakeshore habitats were sampled. The green frog was the most common ranid found and the mink frog was the least common. The bullfrog displayed the most restricted distribution, inhabiting pockets around some, but not all, of the major lakes or open bog areas. In three other areas where

bullfrog breeding choruses were recorded in 1958 (Lower Baraga, White Deer, Bulldog Lakes), the largest number of individuals counted, based on calls, was six.

The only discrepancy between the general survey of the Forest and the individual habitat studies was that the former revealed greater numbers of leopard and mink frogs, and lesser numbers of bullfrogs in the bogs. However, in the habitat study the bog grid was located in only one part of a larger bog area, where both leopard and mink frogs were more abundant.

In comparing all four habitats, amphibian biomass or standing crop was greatest in the bog. On a hectare basis about twice as much amphibian biomass was found in the bog (43,257 grams) as in the pond (26,323) and three and a half times as much in the bog as in the stream (12,164 grams). The hardwoods were the least productive in amphibian biomass, accounting for only 730 grams per hectare. However, the fact that large percents of American toad and spring peeper populations migrate to the woods means that this habitat is important in analyzing energetics, especially because toads were so numerous.

In terms of both biomass and numbers, the American toad ranked at the top in all environments except the bog, where it ranked second only to the green frog; however, such a ranking applies only to the period of time in which the toad is present in these environments. A factor in the movement of energy and nutrients from the low-lying pond areas to higher elevations in the hardwoods is the ability and tendency of populations to move out of breeding areas.

Some sampling was done along the shores of Lower Baraga Lake. In general, the lake-shore populations varied little either in species or approximate numbers from the three aquatic habitats examined above. The type of vegetation that bordered the lake and the period of time sampled were the two most important factors that influenced sampling results along the lake.

The survey revealed the presence of 69 percent (11 of 16) of the amphibian species and 50 percent (5 of 10) of the reptile species known to occur in the central Upper Peninsula. The total of 16 species represents 62 percent of the herpetofauna of Michigan's Upper Peninsula.

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I would like to thank Ron Schauand, Jim Laur, Bob Martignon, Rod Kitchen, Dick Hayes, Rick Eckloff, Kathy Walewski and Mike Altmann for their assistance during the field study. Thanks are also extended to Bill Robinson and Glen Kivela for collection data and sitings. A special note of thanks goes to D. B. DeLury and Richard J. Eckman for their advice on statistical procedures. The work was supported by two Department of Agriculture Research Agreements from the North Central Forest Experiment Station, St. Paul, Minnesota, and a Faculty Research Grant from Northern Michigan University, Marquette, Michigan 49855.

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Describes the means of surveying and estimating the populations of birds, mammals, amphibians, and reptiles in 1972 and 1973 on this 17,000-acre Forest in the Upper Peninsula of Michigan. Gives an annotated list of birds and mammals and estimates biomass of amphibians in four habitats.

OXFORD: 148.2:149:147.6:148.1:U(083.8). KEY WORDS: birds, mammals, amphibians, reptiles, habitat, population estimates, biomass, population densities.

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**Effects of crown release
and fertilizer on small
saw log-sized
YELLOW BIRCH**

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CONTENTS

Diameter Growth Response to Release	2
Bole Quality	2
Response to Fertilization	3
Management Implications	4
Literature Cited	5
Appendix I	5
Appendix II	6
Appendix III	6

EFFECTS OF CROWN RELEASE AND FERTILIZER ON SMALL SAW LOG-SIZED YELLOW BIRCH

Gayne G. Erdmann, Richard M. Godman, and Gilbert A. Mattson

Sternitzke (1974) reported that yellow birch (*Betula alleghaniensis* Britton) saw-er removals exceed growth and that the volume of birch growing stock declined 33 percent in the United States since 1963. The factors, combined with the slow growth of birch in unmanaged stands, has caused serious shortages in saw and veneer required by industry. The quickest improvement in the current situation can probably be made by increasing growth and volume production on potentially high value small saw log-sized trees in such stands. This study was established in 1971 to test crown release and fertilizer treatments aimed at doing exactly that.

Forty-five study trees were selected from a 65-year-old even-aged stand, which was located on the Argonne Experimental Forest in northeastern Wisconsin. Yellow birch comprised about 46 percent of the trees per acre that were 2.6 inches d.b.h. and larger.¹ This proportion is 10 times higher than was commonly found in northern hardwood types of the Lake Superior region (Eyre and Zillgitt 1953). The stand contained 102 saw log-sized trees (9.6 inches d.b.h. and larger) per acre; 80 percent of which were under 13.5 inches. Saw log-sized birch trees occupied codominant crown positions and ranged from 8 to 22 feet taller than the dominant trees largely of other species.

Nine groups of 5 similar trees were selected for the study, making a total of 45 study trees. All of these trees were dominant and well spaced apart. The 45 individual trees within each selected

group for treatment comparisons were well matched as to breast height diameter (d.b.h.), height, stem characteristics, crown size, and density.²

Five treatments were randomly applied to one of the five individual trees within each group. These treatments were four intensities of crown release: 5-foot, two-tree, single-tree, no release, and another single-tree release treatment with fertilizer applied one season later. This provided for nine individual tree replications of each of the five treatments.

Before leaf-out in early May 1971, all crown release thinning was done. Only the most important crown competitor(s) was cut in the single-tree and two-tree treatments. For the 5-foot treatment, all trees whose crowns were within 5 feet of the study tree's crown perimeter were cut. This involved cutting from 5 to 11 trees per study tree (average was 8). About 50 percent of the cut trees were important competitors, the remaining were less important intermediate or suppressed trees.

The next spring, 9 of the 18 single-tree released trees were fertilized. This was done by broadcasting N, P, and K fertilizer using a cyclone seeder on a circular plot (0.01 acre) around each assigned tree (11.78 foot radius).³

More details of special measurements taken and methods used are given in Appendices II and III.

²Initial overall averages for the 45 trees were as follows: height, 73 feet; crown length, 31 feet; crown diameter, 20 feet; and d.b.h., 10.4 inches (range 8.7 to 12.8 inches). Only one of the five-tree groups was under (9.6 inches d.b.h.).

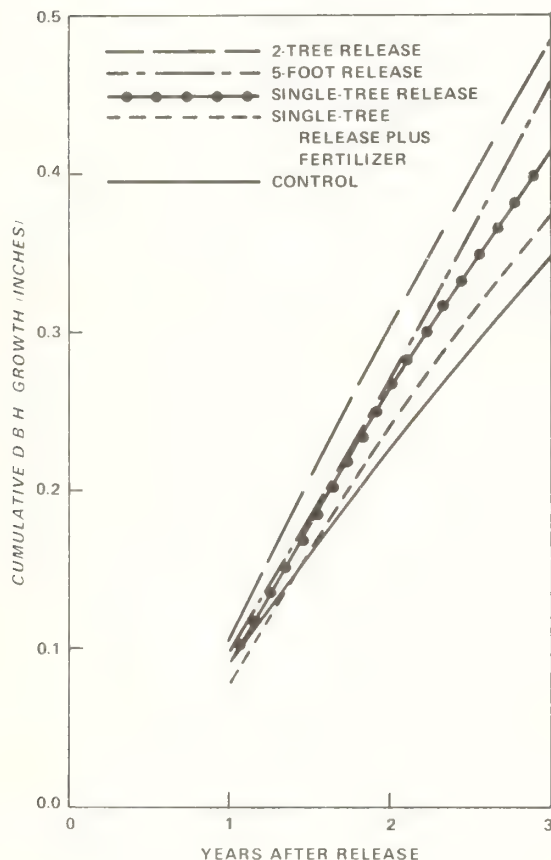
³Each nutrient was applied at 100 pounds per acre (elemental basis).

¹See Appendix I for percent of trees 2.6 inches d.b.h. and larger by basal area as well as for other stand conditions before treatments were applied including soil and other conditions.

DIAMETER GROWTH RESPONSE TO RELEASE

Diameter growth of all saw log-sized trees gradually increased during the 3-year period following crown release. The amount of growth was generally related to the degree of release (fig. 1). However, well-defined

Figure 1.--Mean cumulative diameter growth by treatments and years after release.



trends were not apparent until after the second growing season following release; statistical differences in annual diameter growth rate did not become significant (0.05 level) until after the third growing season. There were no significant differences in growth rate between the control, single-tree release, and the single-tree release plus fertilizer treatments. During the 3-year period, trees released 5-feet beyond the crown perimeter and those released from two competitors outgrew the unreleased trees by

42 percent and 50 percent, respectively, as shown in the following tabulation:

Crown release	Three-year diameter growth (inches)
No release (control)	0.35 a ⁴
Single-tree plus fertilizer	0.37 ab
Single-tree	0.41 abc
5-foot	0.45 bc
Two-tree	0.48 c

Part of the increase in diameter growth was probably related to the gradual build-up in crown size and density as well as to the additional growing space. Increases in crown width and effective crown area, brought about by greater lateral branch elongation in released than unreleased trees, appeared to be the most important factors in crown build-up.

Change in foliage density was not as apparent in this study as observed in pole-size trees over the same period of time (Erdmann and Peterson 1972). The vigorous growth of epicormic sprouts that quickly filled-in the crowns of released pole-size trees was nearly absent in these small saw logs. Differences in crown length caused by height growth and retention of lower branches did not appear to influence diameter growth of the saw log-sized trees.

BOLE QUALITY

Butt logs of study trees were graded (Hanks 1971): 67 percent of the selected trees qualified as grade 3 at the beginning of the study. Only 11 percent were large enough in diameter and free of defects to be assigned grade 2. The remaining trees were below minimum size for any tree grade. Merchantable log height (to a variable top diameter of not less than 8.0 inches) ranged from one-half to one and one-half logs, averaging only one log. However, all study trees were estimated to have a height potential of at least two 16-foot logs. Thirty-one percent appeared to have a two and one-half-log potential and 13 percent a three-log potential; further development was restricted by crown breakup caused by forked limbs, or excessively large limbs.

⁴Values followed by same letter in column are not significantly different (0.05 level) using Duncan's New Multiple Range Test.

two-thirds of the study trees had forks, all of which occurred at or above 29 feet on the bole.

So far, sapsucker feeding activity has occurred only on exposed birch trees that are growing along the edges of roadways and larger openings within the study area. Bird-lick and epicormic branching have not been problems associated with crown release on trees released up to 5 feet beyond their crown perimeters. Sunscald also has not been proven to be a problem associated with release.

RESPONSE TO FERTILIZATION

Fertilization responses were determined by comparing the growth of single-tree released only with single-tree released plus fertilized trees in each of the nine sample groups. Broadcast fertilization with N, P, and K had no significant influence on diameter growth during the 2-year period following application. Growth of fertilized trees during the season of application exceeded that of the nonfertilized released controls by 5 percent. During the second growing season, however, fertilized trees grew slightly less than those not fertilized.

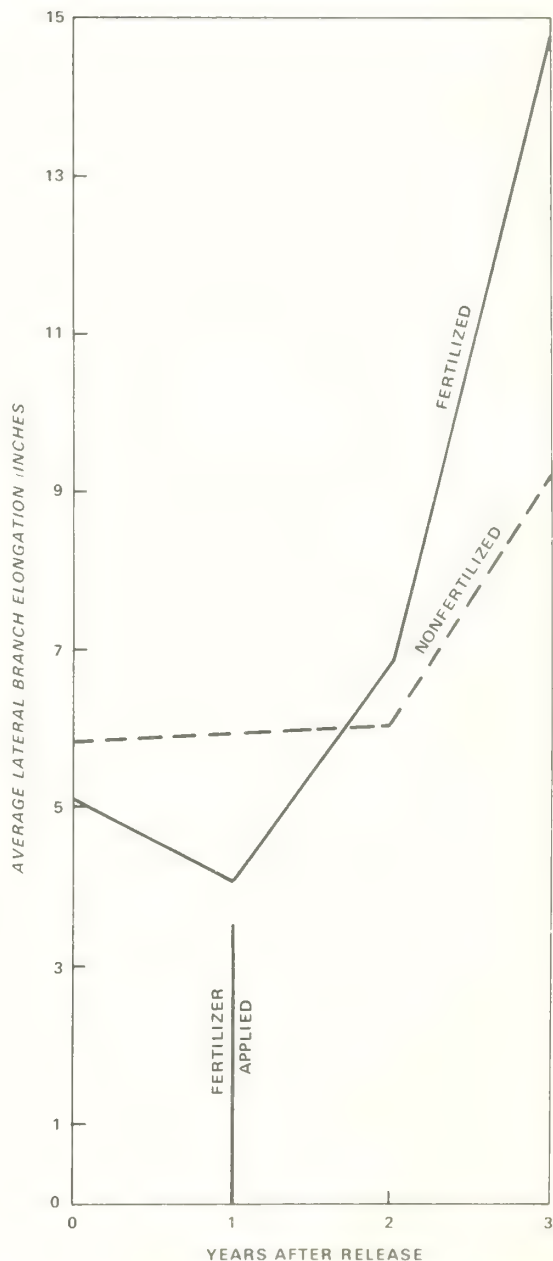
Fertilization increased lateral branch elongation in the upper, free-growing part of birch crowns.⁵ The difference in annual lateral branch elongation between fertilized and nonfertilized trees became apparent at the end of the first growing season following fertilizer application (fig. 2). However, differences first became significantly greater ("t" at 0.05 level) for the nine fertilized trees after the second growing season. Average growth per shoot was 10 inches more for fertilized than nonfertilized trees.

Foliage density was not noticeably improved by fertilization (see Appendix II for foliage density rating procedure). However, the fertilized trees probably had more leaves on the longer lateral shoots produced after fertilization because the number of leaves on a shoot and its length are positively correlated.⁶

⁵Annual lateral branch elongation was measured to the nearest $\frac{1}{8}$ inch on clipped branch tips in 1972 and 1973. Measurements of lateral branch growth were made on branches between terminal bud scars from the branch tip toward the bole.

⁶F. T. Metzger. Unpublished data on foliage density at the Northern Hardwoods Laboratory, Marquette, Michigan.

Figure 2.--Effect of fertilization when applied 1 year after release on mean annual lateral branch elongation of single-tree released birches.



Although there was no change in diameter growth rate, foliar analyses showed that the uptake of P and K was promoted by fertilization (see Appendix III). Both the percent

concentration and absolute amount (or total content) of P and K in leaves of fertilized trees were significantly higher during the growing season during which fertilizer was applied than the season before application (table 1). In August 1973, two growing seasons after fertilization, absolute amounts (milligrams per leaf basis) of P and K in foliage of fertilized trees dropped to pre-fertilizer treatment levels. There were significantly lower absolute amounts of Ca and Mg in leaves of individual trees one season after fertilization than one season before fertilization. Average total content of these elements per leaf were not different in fertilized and nonfertilized trees after the second season following fertilization (table 2).

Leaf percentage values were not reliable indicators of the nutrient status of the leaves; similar results were also reported for birch (Hoyle 1965). For example, the percentages of P and K in fertilized

tree foliage were significantly higher in 1973, the season after fertilization, than in 1972, the season of fertilization. These results could lead one to incorrectly conclude that nutrient uptake was greater one season after fertilizer application when, in fact, absolute content of elements per leaf was actually significantly lower (table 1). The significantly higher P and K percentage values resulted from significantly lower fertilized tree leaf weights in 1973 than in 1972. One other noticeable effect of fertilization during the first 2 years was that foliage in crowns of fertilized trees remained green after the other trees had turned yellow.

MANAGEMENT IMPLICATIONS

Early results indicate that previously untended 65-year-old codominant yellow birch trees will respond to crown release but the increase in diameter growth rate will occur

Table 1.--Change in the average composition of single-tree released plus fertilized birch foliage from one growing season before to two seasons after fertilization¹

Sampling time	N	P	K	Ca	Mg
<i>Percent dry weight</i>					
Season before fertilization	2.14	20.24c	0.74c	1.18b	0.36a
Season of fertilization	(²)	.31b	1.31b	1.05b	.35a
Season after fertilization	2.80	.45a	1.47a	1.49a	.36a
<i>Milligrams per leaf</i>					
Season before fertilization	5.64	0.66b	1.98b	3.24a	0.99a
Season of fertilization	(¹)	.82a	3.46a	2.93a	.95a
Season after fertilization	2.66	.44b	1.45b	1.43b	.34b

¹Foliage was collected in August (1-10) of 1971, 1972, and 1973 from the nine single-tree released plus fertilized trees.

²Values followed by the same letter in a column are not significantly different (0.05 level) using Duncan's New Multiple Range Test.

³Nitrogen analyses were not made in 1972.

Table 2.--Average concentrations and absolute amounts of elements in birch foliage by treatments after fertilizer application

Treatment	N	P	K	Ca	Mg	Al	Fe	Zn	Cu	Mn	B
<i>Percent dry weight</i>						<i>ppm</i>					
Released only	12.70a	0.34b	1.14b	1.63a	0.41a	59a	118a	240a	9a	955b	82a
Released plus fertilized	2.80a	.46a	1.47a	1.49a	.36b	56a	123a	241a	9a	1,326a	80a
<i>Milligrams per leaf</i>						<i>Micrograms per leaf</i>					
Released only	3.71a	.46a	1.60a	2.08a	0.56a	81	157	334	12	1,462	109
Released plus fertilized	2.66a	.44a	1.45a	1.43a	.34a	51	117	106	9	1,202	82

¹Values followed by the same letter in a column are not significantly different (0.05 level) using Duncan's New Multiple Range Test.

ually. Adjustments of the crown to the increased growing space and to change in density apparently require about 3 years before significant diameter growth becomes apparent. Release by removing two important competitors has shown the most response immediately following treatment. Although response to the 5-foot release treatment, which removed twice as many important competitors, was similar, the greater growing space does suggest longer benefits.

In the Lake States there are about 8 million acres of immature second-growth northern hardwood stands under 75 years of age. Most are dense, unmanaged, even-aged stands that developed after heavy commercial logging. Potentially valuable yellow birch stands growing under these conditions need to be crown released to assure their survival and stimulate growth. In this study, individual basal area density around individual evenly spaced saw log trees averaging 10.4 inches d.b.h. in the 5-foot and two-tree release treatments averaged 84 and 109 square feet per acre, respectively.⁷ If crown thinning like these were applied under stand conditions, released crop trees normally would not be spaced so far apart. Thus for a stand (includes all trees in the main overstory canopy) of the same diameter, a individual basal area stocking level as low as 30 square feet would still be considered acceptable under Lake States conditions; a slightly lower level of about 75 square feet is recommended in the Northeast (Leak 1969).

In structured stands under uneven-aged management, yellow birch saw log-sized trees should receive special attention during logging so that potentially high value trees can be released from at least two important competitors. These practices should encourage to maintain yellow birch in future stands to increase the growing stock and stimulate development of larger trees required for industrial usage.

⁷Basal area density, a commonly used measure of stand stocking levels, was measured within 26.3 foot radius (1/20-acre plot) of the released trees center at d.b.h.

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APPENDIX I

Trees 2.6 inches or larger averaged 152 square feet of basal area. Yellow birch trees made up nearly 37 percent of the basal area; sugar maple (*Acer saccharum* Marsh.) 18 percent; hemlock (*Tsuga canadensis* (L.) Carr) 18 percent; basswood (*Tilia americana* L.) 9 percent; white ash (*Fraxinus americana* L.) 8 percent; American elm (*Ulmus americana* L.) 5 percent; and white birch (*Betula papyrifera* Marsh.), red maple (*Acer rubrum* L.), black ash (*Fraxinus nigra* Marsh.), and northern red oak (*Quercus rubra* L.) combined 5 percent.

The site indices based on stem analysis were 60 feet at 50 years for yellow birch and sugar maple and at least 5 feet greater at 50 years for basswood and white ash.

The study area is located on a level to gently rolling ridgetop, at an elevation of 1,750 feet. Soils classify as coarse loamy Alfic Fragiorthod primarily of the Iron River series although some areas have thin sand and gravel layers in the substratum that classify as Stambaugh. Effective rooting depth averages about 19 inches with a pH of about 5.3 within this upper layer.

Small boulders are common on the surface and throughout the profile. During the growing season, precipitation averages about 20 inches, but short dry periods are not uncommon.

APPENDIX II

Foliage density was rated after full leaf development each year. Foliage ratings were based on the average percent of the main stem within the tree's live crown that was obscured by foliage when viewed from two sides at one tree-length distance as follows: dense (87.5 or more), medium to dense (75 to 87.5), medium (62.5 to 75), fair to medium (50 to 62.5), fair (37.5 to 50), and poor (37.5 or less).

APPENDIX III

Each year foliage samples were collected from single-tree released fertilized and non-

fertilized birch trees during the first week in August as recommended by Hoyle (1965). A sample of 25 to 68 mature sun leaves was taken from fully exposed upper branches on the south side of the crown at each occasion. Leaf samples were dried at 70° C, ground in a Wiley mill to pass a 20-mesh screen, and analyzed for nutrient concentrations. Total nitrogen was determined using a semimicro-Kjeldahl method (Bremner 1965); P, K, Ca, Fe, Al, Cu, Zn, B, and Mn determinations were made on dry-ashed (470° C for 4 to 5 hours) samples on the emission spectrophotograph. These were made in 1971 and 1972 under the guidance of Donald R. Christenson, Associate Professor, Crop and Science Department, Michigan State University, East Lansing, Michigan. In 1973 these analyses were made by the Crop Research Laboratory, University of Minnesota. Paired t-tests were made to compare differences on foliage composition for each element between sample means.

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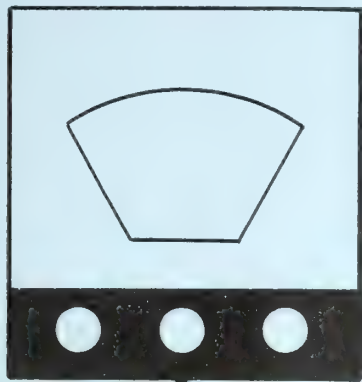
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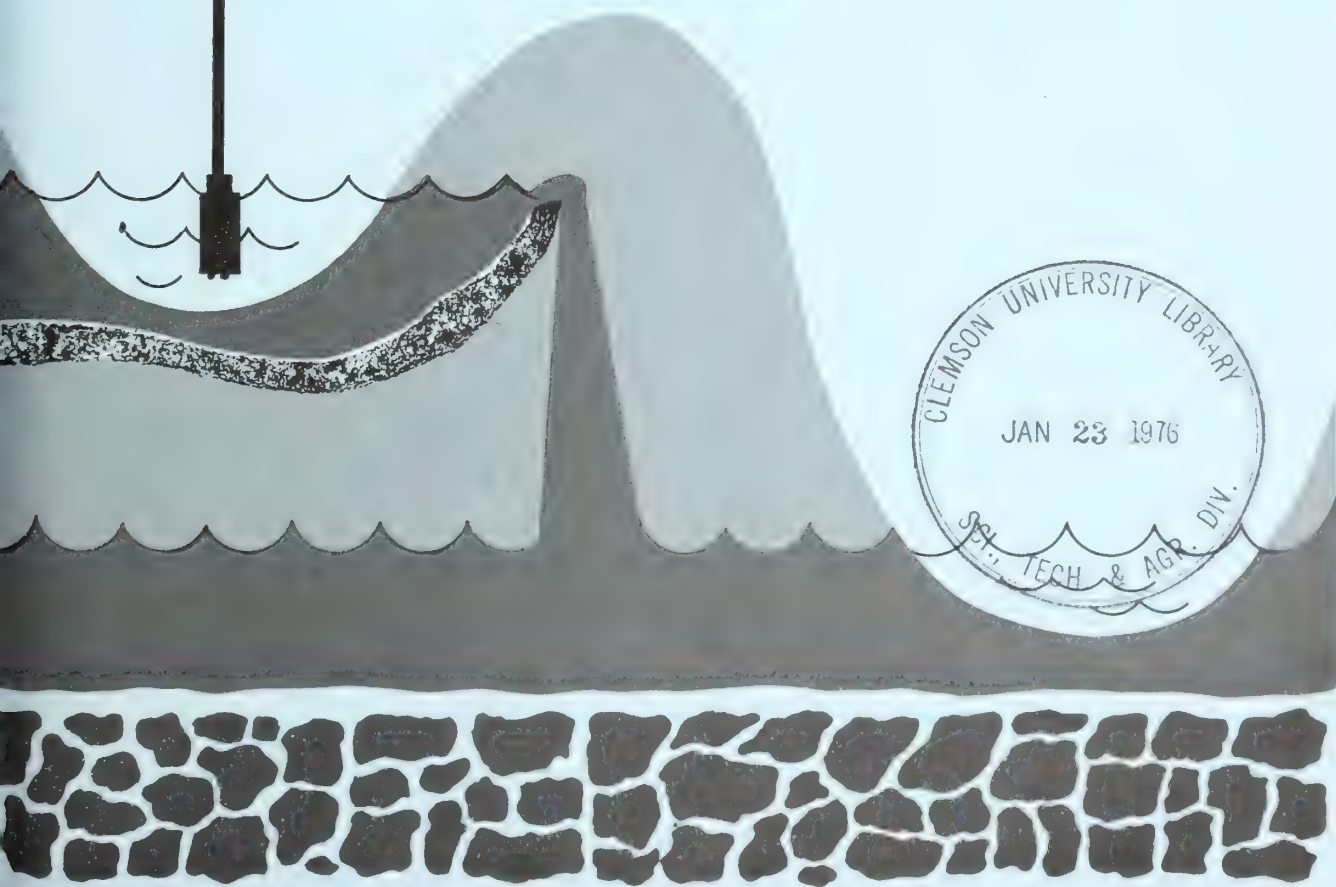
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SPECIFIC CONDUCTANCE IDENTIFIES PERCHED AND GROUND WATER LAKES

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SPECIFIC CONDUCTANCE IDENTIFIES PERCHED AND GROUND WATER LAKES

Clarence F. Hawkinson and Elon S. Verry

In north-central Minnesota the water level in lakes may or may not be contiguous with the regional water table. Some lakes are perched above the regional water table and receive water primarily from precipitation and local runoff. Other lakes are simply an exposure of the regional water table and receive large amounts of ground water. In areas with many lakes, the knowledge of which lakes are ground water fed can be used to draw general maps of the regional water table by taking the elevation of ground water lakes as control points to construct contours.

A study to evaluate the usefulness of specific conductance (the ability of water to pass a standard electrical current) as an index of water type in lakes was conducted on a 30-square-mile area near the Marcell Experimental Forest in north-central Minnesota (ca. N 47° 32' Lat., 93° 28'W Long.) (fig. 1).

METHODS OF STUDY

The regional water table was measured by means of 29 wells ranging from 11 to 72 feet deep. One well was fitted with a continuous recorder for water table fluctuations. The others were measured each month for 10 years. Portable field meters were used to measure specific conductance and pH for each of 17 area lakes; all values were corrected to 25°C.

The lowest water table elevation in each well during the 10-year period was used to draw a 5-foot contour map of the regional ground water surface (water table) (fig. 2). Elevations of lakes known to reflect the water table were also used in drawing contours. Arrows were drawn at right angles to the ground water contour lines to indicate the general direction of flow.

RESULTS

Specific conductance values fell into three distinct categories which we termed perched, transitional, and ground water lakes. pH values generally followed the same pattern but lacked the sensitivity of specific conductance (table 1).

Table 1.--*Specific conductance and pH of lakes at 25° C*

PERCHED LAKES		
Lake	Specific conductance μmhos	pH units
Blandin	16	6.2
Willeys	16	6.6
White Porky	18	6.6
Moss	19	6.8
Moon	19	6.4
Spring	20	6.4
Lum	21	6.3
Sawyer	22	6.1
Bog	23	6.6
TRANSITIONAL LAKES		
Burrows	31	6.4
Lost Moose	55	7.4
Burnt Shanty	32	6.9
Buchman	95	8.3
GROUND WATER LAKES		
Sand	144	7.5
Hunter	150	7.5
Cutaway	160	7.6
Lake 19	192	7.2

Perched lakes are fed by precipitation and local runoff. Local runoff is principally subsurface flow resulting from water percolating about 6 inches into the soil and flowing laterally down-slope over the top of a buried clay horizon. Because of these sources, perched lakes have a low mineral content and thus low specific conductance (16 to 23 μmhos) and a low pH (near 6.4).

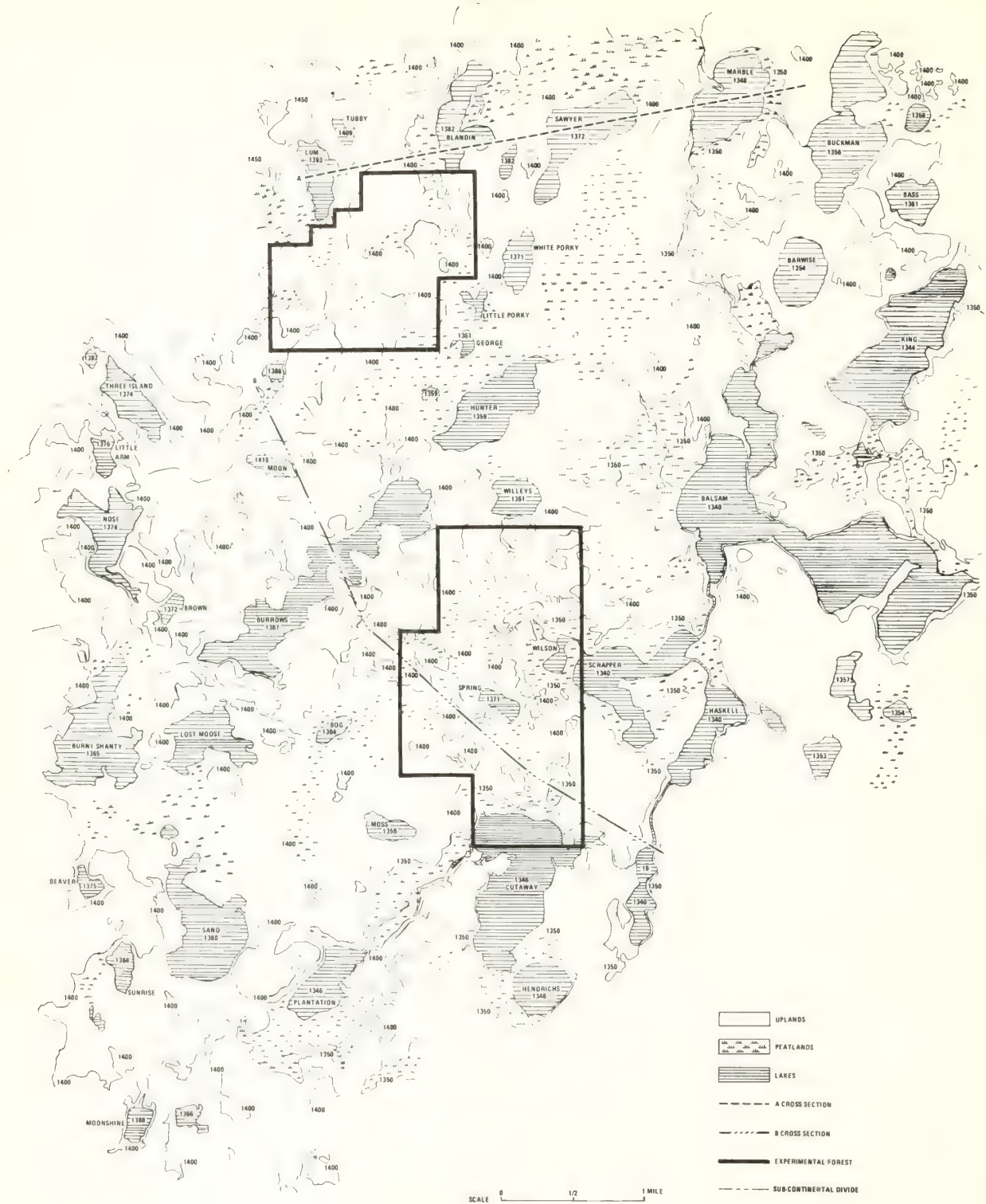


Figure 1.--Surface contour map (50 foot intervals MSL) of 30 square mile area that encompasses the two units comprising the Marcell Experimental Forest.

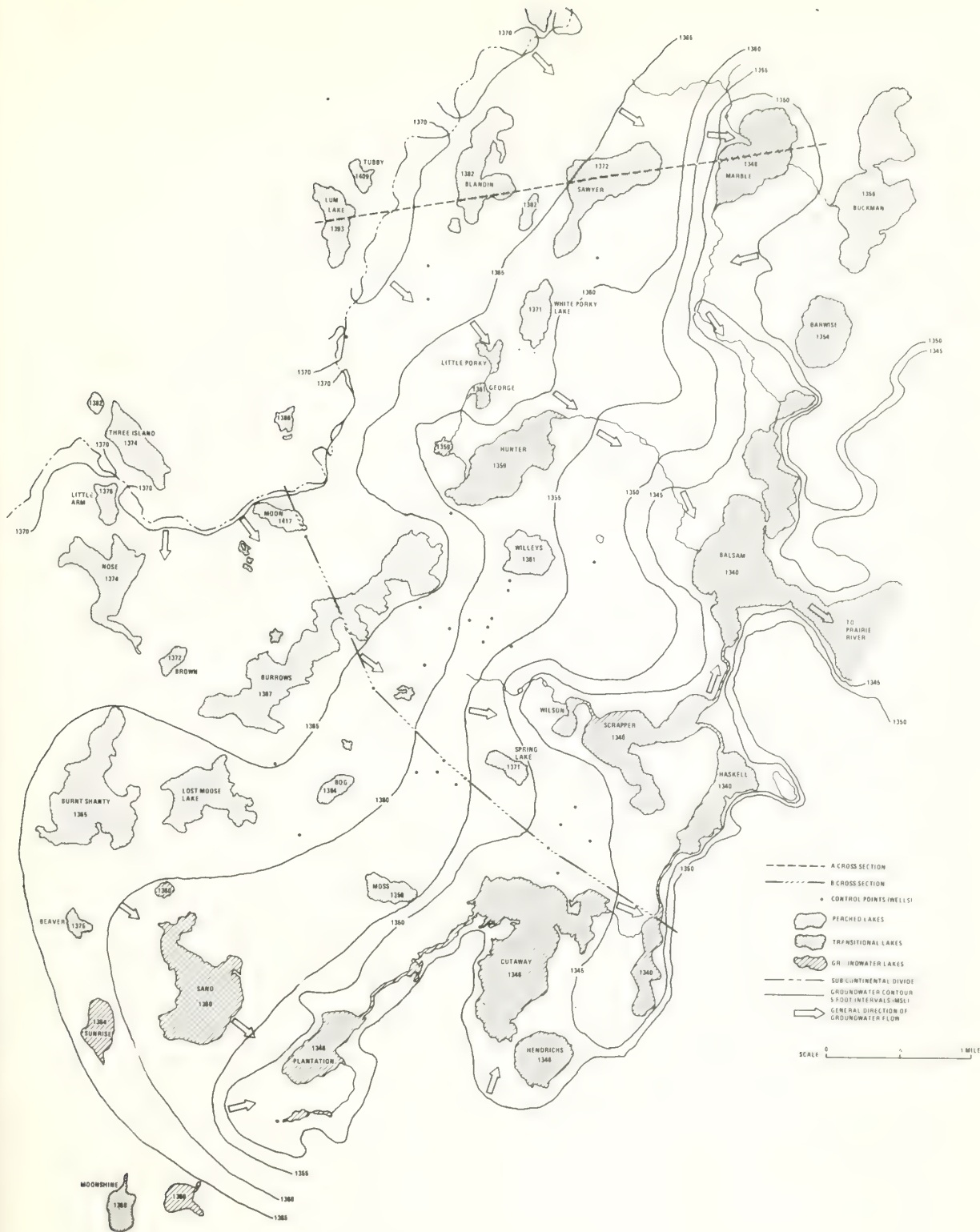


Figure 2.--Water table map of 30 square mile area that encompasses the two units comprising the Marcell Experimental Forest.

Ground water lakes receive the same inflow as perched lakes plus a lot of ground water inflow. Ground water entering a lake has traveled some distance through soil parent materials and aquifer sands and contains a high concentration of dissolved minerals, particularly calcium. Correspondingly, specific conductances range higher (144 to 192 μ mhos) with a pH of about 7.5.

Transitional lakes in this study have specific conductances ranging from 31 to 95 with a pH of about 7.2. Their water may vary considerably, tending toward perched lakes following snowmelt, and ground water lakes during dry periods.

These classifications were confirmed by a ground water contour map showing water table elevation and direction of flow (fig. 2). Two cross sections were drawn to illustrate relative positions of the ground surface, the lakes, the top of the sand aquifer, and the water table (cross sections A and B, fig. 3).

The water table ranged from 5 to 65 feet below the ground surface at its lowest fluctuation. Annually it fluctuates slightly less than a foot, but over the 10-year period it fluctuated 2-1/2 feet. The aquifer is mostly below a thin layer of glacial till. This till layer separates some lakes and bogs from the ground water system and prevents their water from seeping into the regional ground water system.

Some lakes are perched high above the regional water table; for example, Moon Lake in the west-central part of the study area (cross section B, fig. 3) is more than 40 feet above the regional water table. Many bogs in the area are also perched above the regional water table.¹

Other "perched" lakes may sit in the ground water system but still be separated from the ground water by lake bottom muds of an organic nature, by till, or by other impervious material. Sawyer Lake in the northeast corner of the study area is an example (cross section A, fig. 3).

Lakes such as Burrows and the unnamed lake east of Cutaway lake (Lake 19) are exposures of the water table (cross section B, fig. 3). No stream flows into or out of Burrows Lake; it probably feeds the ground water system during periods of high precipitation and

runoff, and depletes ground water during periods of high evaporation. On the other hand, the unnamed lake and the stream leading from it discharge ground water.

APPLICATION

The correlation between specific conductance and source of water in a lake can be useful in drawing water table maps in areas with many lakes. Needed are only specific conductance values for the lakes (measured during a relatively short period to avoid biasing by large storms) and a surface topographic map (usually available from the U.S. Geological Survey). Specific conductance should not be measured during or within 2 weeks following snowmelt as all values will be low due to dilution. When ground water lakes are identified, crude water table contours can be drawn by using the ground water lake elevations as a control.

Water table maps are useful for planning wells by subtracting water table elevations from surface elevations to obtain depth to water. In our study area we found that the highest level of the water table occurred in early July as a delayed result of spring snowmelt; the lowest are usually in March. Water table maps are also useful for locating land fills and sewage renovation areas by knowing the direction of ground water flow and the depth of soil and parent materials above the saturated zone.

The ranges of specific conductance for perched, transitional, and ground water lake in this study are only relative. Sampling at different times of the year would show different ranges, as would sampling in different areas. Still, specific conductance sampling if done over a short period (2 weeks or so) will indicate the existence of perched, transitional, or ground water lakes. Although the extent of perched lakes State-wide is not known, they have been identified in the Suomi Hills area 15 miles west of the Marcel study,² and in the pothole region of west-central Minnesota.³

² J. Roles, M. B. Hathaway, W. Allen, G. Goltz, J. Mathisen, J. Osborne. *Proposed Suomi Hills area management plan*. USDA For. Serv. Chippewa Natl. For., Cass Lake, Minn. 60 p. 1974.

³ G. M. Schwartz and P. W. Manson. *Pothole drainage and deep ground water supplies*. Minn. Farm & Home Sci. 21(3):13-15. 1964.

¹ R. R. Bay. *Factors influencing soil moisture relationships in undrained forested bogs*. In *Int. For. Hydrol. Symp. Proc.*, Penn. State Univ. p. 335-343. 1967.

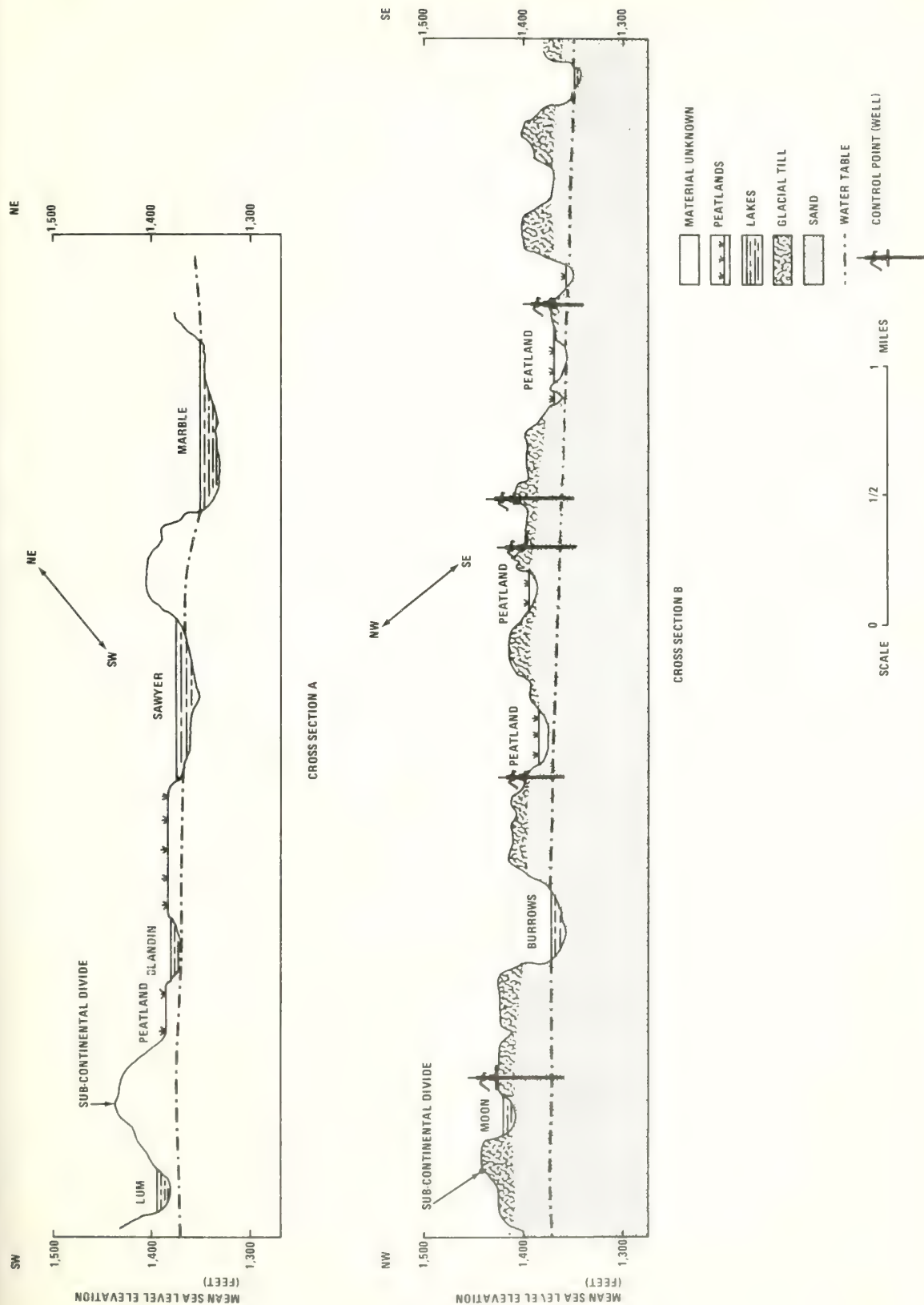


Figure 3.--Two cross sections of ground water and lakes in 30 square mile area that encompasses the two units comprising the Marcell Experimental Forest.

Hawkinson, Clarence F., and Elon S. Verry.

1975. Specific conductance identifies perched and ground water lakes. USDA For. Serv. Res. Pap. NC-120, 5 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Shows that lakes can be classified into perched, ground water, and transitional categories according to specific conductance values. Confirms the classification with 10 years of water table measurements in 29 wells and discusses several applications of lake specific conductance values.

OXFORD: 116.9--014(047.3)(776). KEY WORDS: water table, limnology, land management, water quality, maps.

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PRUNING

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**PIN OAK
IN
SOUTHEASTERN
MISSOURI**

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CONTENTS

Methods	1
Results	1
Effect of Pruning	1
Correlation of Numbers of Branches	
Before and After Pruning	2
Effect of Season of Pruning	3
Distribution of Branches	
on North and South Sides of the Bole	3
The Effect of Direct Sunlight	
on Branching and Tree Growth	3
Effect of Pruning on Diameter Growth.	3
Discussions and Conclusions.	3
Summary.	4
Literature Cited	4

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PRUNING PIN OAK IN SOUTHEASTERN MISSOURI

Robert A. McQuilkin

Pin oak (*Quercus palustris* Muenchh.) is an important tree species on bottomlands and poorly drained upland flats in the central United States. It is characterized by rapid height and diameter growth, a straight, strongly excurrent main stem, and many dead branches which persist for many years on the lower bole. These branches cause many small knots and subsequently much loss of value in pin oak lumber (Minckler 1965).

In 1957, a study was installed to determine: the feasibility of pruning pin oak, the degree of epicormic branch sprouting that would occur after pruning, and what factors would affect this sprouting. Early results of this study have been published (Minckler and Krajicek 1964). This report gives the results to 1969--12 and 13 growing seasons after pruning.

METHODS

A complete description of the study area and the experimental methods is given by Minckler and Krajicek (1964). Briefly, the study was designed to test the effect of season of pruning (before, during, or after the growing season) and the effect of exposure of the bole to direct sunlight on the number and spatial distribution of epicormic branches after pruning. Treatments were assigned at random to 150 dominant and codominant trees within a 30-acre portion of a 30- to 35-year-old even-aged, fully stocked pin oak stand in the Mingo National Wildlife Refuge, Stoddard and Wayne Counties, Missouri. In March, 1957, the first 16-foot log was pruned on 40 trees and 10 nonpruned control trees were designated; half of these trees (20 pruned and 5 nonpruned) were exposed to direct sunlight by cutting 1 to 3 trees on the south and southwest sides of the study trees.

This entire procedure was repeated in June and again in October, 1957. All pruning was done manually with pruning saws.

The number of live and dead branches on the first log was recorded by tree side (north-northeast and south-southwest) before pruning and 1, 4, and 12 years after treatment. Tree diameter and crown class were also measured. The 12th year measurements were taken on all trees in October, 1969. Since the initial measurements were taken at the time the treatments were applied (March, June, and October, 1957), the data represent 13 growing seasons for the March trees, 12.5 growing seasons for the June trees, and 12 growing seasons for the October trees. Adjustments for these differences in time were made in the analyses where necessary. Of the 150 original study trees, 2 died and 28 had dropped below the codominant crown class by 1969. The results presented here are based on the remaining 120 trees (96 pruned and 24 nonpruned).

RESULTS

Effect of Pruning

Although there was some epicormic branch sprouting after pruning, in 1969 the pruned trees still had less than one-fourth the number of branches on the first 16-foot log as the nonpruned trees--6.1 vs. 25.6 branches (table 1). This difference was statistically significant at the $P = .001$ level. Almost all sprouting on the pruned trees occurred within the first 4 years after pruning; for the remaining 8 years of the study, the mean number of branches per tree remained about constant (fig. 1). The number of branches on the nonpruned trees declined 32 percent over the study period, from 37.7 in 1957 to 25.6 in 1969.

Table 1.--Mean numbers of branches¹ on the first 16-foot log of pruned and nonpruned pin oak trees by month, shading, and tree side

Month pruned	South half of bole			North half of bole			Sum of north plus south halves ²		
	Exposed	Shaded	Mean	Exposed	Shaded	Mean	Exposed	Shaded	Mean
March	2.6	4.5	3.4	0.5	2.1	1.2	3.2	6.6	4.7
June	4.4	3.6	4.1	0.5	2.1	1.2	4.9	5.7	5.3
October	9.4	3.8	6.6	2.6	1.2	1.9	12.1	5.0	8.5
Mean of all pruned trees	5.3	4.0	4.7	1.2	1.8	1.5	6.5	5.8	6.1
Mean of all nonpruned trees	17.2	13.2	15.4	11.7	8.5	10.2	28.9	21.7	25.6

¹ Live plus dead branches.

² Sum of north plus south half values may not add exactly due to rounding.

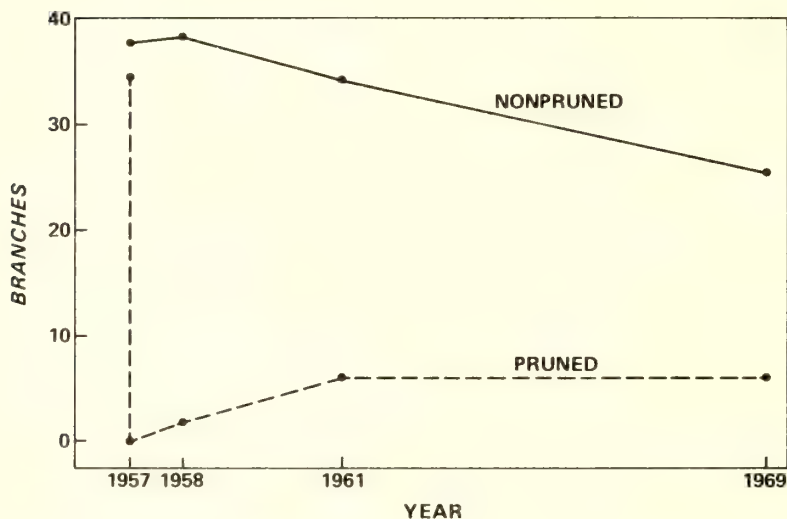


Figure 1.--Mean number of live plus dead branches (north plus south sides) on the first 16-foot log of the pruned and nonpruned trees from 1957 through 1969.

Eighty-two percent of the branches on the nonpruned trees and 66 percent on the pruned trees were dead in 1969.

Correlation of Numbers of Branches Before and After Pruning

The number of new branches on the pruned trees was weakly correlated with the number of branches before pruning: (branches = $.52 + .163$ (branches in 1957) in 1969)

Although the R^2 was only .12 ($r = +.35$), the regression was statistically significant at the $P = .01$ level. Thus, for every 10 branches on the first log of a tree before pruning, $1\frac{1}{2}$ to 2 new branches can be expected after pruning. The data indicate however, that there will be a great amount of variation around this expected value. This correlation of branch numbers before and after pruning is presumably due to genetic control of branching characteristics within the individual trees.

Effect of Season of Pruning

Because of the correlation between branches before and after pruning, analyses of the 1969 pruned tree data was done by covariance analyses on the regressions:

$$\text{branches (1969)} = b_0 + b_1 (\text{branches in 1957}).$$

This technique permitted tests to be made on the 1969 pruned tree data after the effect of number of branches in 1957 was removed. Analysis of differences in total branches for the exposed and shaded trees by months of pruning showed season (month) of pruning had no effect on branch sprouting (table 1). All month comparisons were statistically nonsignificant with the exception of the exposed October trees. The mean number of branches for this treatment (12.1) was significantly higher than for the exposed March or June trees (3.2 and 3.9 branches); this greater value was, however, due primarily to 5 trees (out of 16) which inexplicably had from 21 to 37 branches each (the mean number of branches on the other 11 trees in this treatment was 5.8). The mean number of branches for the shaded October trees was 5.0--less than the comparable values for the shaded March and June trees (6.6 and 5.7 branches). Because of the small number of trees which caused this high value and the lack of a similarly high mean for the shaded October trees, the high exposed October value is most likely a chance occurrence, and not due to either month or exposure treatment.

Distribution of Branches on North and South Sides of the Bole

Overall, approximately three-fourths of the new branches on the pruned trees grew on the south-southwest half of the bole (table 1). Differences were analyzed by t-test; adjustment for number of branches before pruning was not made because these north-south comparisons were made on two halves of the same tree. Differences for both pruned and nonpruned trees were significant at the $P = .001$ level.

The Effect of Direct Sunlight on Branching and Tree Growth

The effect of exposure to direct sunlight was analyzed by the previously

described covariance technique to remove the effect of the number of branches before pruning. Exposure of the trees to direct sunlight on the south-southwest side had no effect on the number of new branches on the pruned trees (table 1). Differences in branch numbers between exposed and shaded trees were statistically nonsignificant except in the case of the October trees. As explained before, the differences in these trees were interpreted as being not due to treatment. However, exposure did affect the distribution (by tree side) of the branches; the proportion of branches growing on the south side of the trees was 82 percent for the exposed trees and 69 percent for the shaded trees. This difference was significant at the $P = .05$ level.

Exposure of the trees by cutting several adjacent trees (in effect, a partial thinning) resulted in a 30 percent increase in diameter growth of the exposed trees compared to the trees which remained completely shaded. Evaluation of the data was by covariance analysis with diameter growth adjusted for initial (1957) diameters. Assuming an initial diameter of 8.0 inches in 1957 and using the average growth period for all treatments (12.5 growing seasons), the exposed trees grew 3.24 inches (.26 inches per year) while the shaded trees grew 2.48 inches (.20 inches per year). This difference was significant at the $P = .001$ level. This 30 percent increase in diameter growth agrees with results from other studies which have shown that pin oak responds well to thinning or release (Minckler 1953, Minckler 1965, Minckler 1967). Exposure of the trees had no effect on height growth.

Effect of Pruning on Diameter Growth

Although the pruned trees had a 16.5 percent greater diameter growth than the nonpruned trees, this difference was not statistically significant. Because all the bole branches on these trees were small and most (76 percent) were dead at the time of pruning, no significant effect on diameter growth by pruning was expected.

DISCUSSION AND CONCLUSIONS

Mechanical pruning is a feasible method of permanently reducing the number of branches on pole-size pin oak in fully-stocked or partially thinned stands. Regrowth of branches was confined almost

entirely to the first four years after pruning, and presumably (unless perhaps the stand is opened up greatly), the number of branches will remain about the same or decline slowly as the stand gets older. It is interesting to speculate what would have happened if, four years after the pruning, a second pruning had removed the few branches which did sprout. Would more branches have sprouted, or would the trees have remained essentially branch-free after that?

The strong correlation of branching with bole side (aspect) suggests that pin oak branching is strongly affected by light intensity. If this assumption is made, it is then difficult to explain why further exposure to light by cutting adjacent trees did not stimulate even more branching. Although most of the comparisons between exposed and shaded trees in table 1 were not statistically significant, the data (disregarding the October trees) suggest that, if anything, the additional exposure actually reduced the number of branches on both the north and south sides of the trees. For the March and June pruned trees, the south-side mean numbers of branches in 1969 were: exposed = 3.5, shaded = 4.1; the north-side means were: exposed = 0.5, and shaded = 2.1. This last difference was significant at the $P = .01$ level.

An economic analysis of pin oak pruning is not possible until the trees become larger than their present (1975) estimated mean d.b.h. of about 12 inches. The minimum top diameter (inside bark) for hardwood Grade 1 logs is 13 inches; assuming a form class of .78 (Jensen and Woerheide 1956), these pin oak will need to have a d.b.h. of around 17 inches to be potential Grade 1 logs.

Although a definitive economic analysis cannot be done now, an indication of significant improvement in log quality and value can be inferred from a statement by Boyce and Schroeder (1963) concerning the effect of pruning on hardwood log quality: "...pruning...will result in little or no gain in log quality unless the practice reduces the number of grading defects in the butt log to less than 8." Branches and branch stubs are the main grading defects in pin oak. The mean number of branches on the butt log of pruned trees in 1969 was 6.1; 72 percent of the logs had less than 8 branches, and 49 percent had less than 4 branches. In comparison, the mean number

of branches on the nonpruned trees was 25.6, and only 7 percent of these trees had less than 8 branches on the butt log. Final economic analysis will require a lumber grade recovery study on logs from pruned and nonpruned trees to accurately assess the overall effects of pruning and, in particular, to assess the effect of the unequal lateral distribution of sprouts on lumber grade yields.

SUMMARY

Based on this study, the following conclusions and recommendations can be made regarding pin oak pruning:

1. Pruning will significantly and permanently reduce the number of branches on the butt logs of pole-size pin oak.
2. Wherever possible in the selection of trees to be pruned, trees with fewer branches should be chosen over those with more branches; this will result not only in lower pruning costs, but also in fewer epicormic branches after pruning.
3. Pruning can be done at any time of the year without affecting the number of new sprouts after pruning.
4. Pruning can be combined with at least light thinning to increase the diameter growth of the trees without increasing the number of new sprouts after pruning.
5. Consideration should be given to making a second pruning four years after the first pruning to remove the few new branches that will grow on most trees. Assuming that the sprouting after this second pruning would be very light, boles nearly free of branch and clear, knot-free lumber would result.

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For. Exp. Stn., St. Paul, Minn.

Describes the effects of pruning, season of pruning,
shading, sunlight, and side of tree on epicormic branching
and quality of first 16-foot log.

OXFORD: 815.4:181.63:176.1. *Quercus palustris* (778).
KEY WORDS: epicormic, branches, sprouts, log quality.

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GROWTH, RY WEIGHT YIELDS, and SPECIFIC GRAVITY



**... OF 3-YEAR-OLD
POPULUS GROWN
UNDER INTENSIVE
CULTURE**

**DAVID H. DAWSON
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GROWTH, DRY WEIGHT YIELDS, AND SPECIFIC GRAVITY
OF 3-YEAR-OLD POPULUS GROWN UNDER INTENSIVE CULTURE

David H. Dawson, J. G. Isebrands, and John C. Gordon

A common goal in agriculture for some time has been to systematically "optimize" all the manageable factors of plant environment. This concept has led to maximum crop yields for a particular site. Conversely, in forestry, practical silviculture has been applied as a single practice, with the hope of improving yields of natural stands, or emulating natural stands in the form of plantations.

Although woody plants can have biomass yields comparable with those of annual crops (Gordon 1975), their full photosynthetic potential will be realized only through research that specifies new modes of culture (Larson and Gordon 1969). Maximum growth can be attained if woody plants with ideal characteristics are grown under the best environmental conditions possible in the field.

The environmental factors most easily manipulated under field conditions are soil moisture, soil nutrients, and plant spacing. Spacing is particularly important because it is easily manipulated and does much to determine tree form and wood quality (Larson 1962).

In the search for "optimum" environments for particular genotypes, the concept of the ideal plant type, or ideotype, has proven useful. The specification of ideal plant characteristics, for a given cultural environment, provides a target for selection and breeding. For example, an ideal wood fiber-producing tree would have the following characteristics: (1) rapid proliferation of leaves in the spring and late senescence of leaves in fall; (2) erect branching, acute leaf angles, and a high leaf area index for maximum solar radiation interception; (3) noncompetitiveness, so that each individual in a stand efficiently occupies only the space allocated to it; (4) maximum allocation of photosynthate to stem wood production;

(5) maximum response to available nutrients, particularly nitrogen; and (6) desirable wood properties for proposed end product¹ (Dickmann 1975).

Several efforts have been made using the above concepts to exploit the greater interception of solar energy by employing high initial densities and short rotations (McAlpine *et al.* 1966, Smith and DeBell 1973).

The experiment reported here was conducted to determine the effects of plant spacings on the growth, dry weight yield and distribution, and specific gravity of a single *Populus* genotype (*Populus* 'Tristis #1') subjected to near-optimum field cultural conditions for 3 years in northern Wisconsin. Crist and Dawson (1975) have reported on 2-year results. Although there have been many spacing experiments with members of the genus *Populus*, we know of none that have included close spacings, intensive water and nutrient management and monitoring, and total assessment of yield of all plant components over short rotations. Our results show that yields much higher than those attained by conventional forestry methods are possible.

METHODS AND MATERIALS

The study was established in an irrigated nursery near Rhinelander, Wisconsin, in June, 1970, using 8-in. long, unrooted cuttings that were approximately 0.25 inch in diameter. Biweekly foliar analyses were

¹ Philip R. Larson. *Physiological parameters of intensive culture--theoretical and applied. In-Service Workshop on Intensive Culture, Rhinelander, Wis., Sept. 18-19, 1973.*

used to monitor nutrient status, and fertilizers were added throughout each growing season to maintain near-optimum in-plant nutrient levels (Dykstra 1972). Soil moisture was maintained near field capacity by frequent irrigation (fig. 1).



Figure 1.--Three-yr-old plots of maximum-fiber-yield study.

The study design was a randomized complete block with three replications. The plant spacings were 9 in. by 9 in. (77,440 plants/acre), 12 in. by 12 in. (43,560 plants/acre), and 24 in. by 24 in. (10,890 plants/acre) in 16-ft by 16-ft plots. Plots were kept small because of limited availability of plant material and resources. The spacings will hereafter be referred to as 9 by 9, 12 by 12, and 24 by 24.

Height and basal diameter were measured on a 10 percent sample of the trees in each plot six times during each growing season. To describe crown form, the following were measured on five additional trees per plot: shoot length, internode length, branch length, branch angle, and branch diameter.

After two full growing seasons (end of 1972), a 2-ft by 6-ft subplot was harvested from each of the plots.² Therefore, the number of trees harvested varied depending on the spacing. Trees were cut

at ground level and the following measurements made and recorded for each tree: total height, stem diameter (base, midpoint, and 6 inches from the top); number of branches, length of the uppermost branch, the sixth branch from the top, and the bottom branch; height from base to bottom branch; and length of stem above top branch. At harvest, the stem and branches were cut into 3-ft lengths, wrapped in wet paper towels and polyethylene wrap, and placed in the freezer.

To analyze yield each tree was removed from the freezer and separated into the following components: stem wood, branch wood, stem bark, branch bark, tips (top 6 inches of stem), and dead stem wood. All components were oven-dried at 70°C and then weighed. Dry weight yields were extrapolated to tons per acre by area expansion. Because the trees were harvested after leaf fall had begun, leaf dry weights were not included.

In addition, three discs were removed from three points on the stem (1 inch from the base, midpoint of the stem, and three internodes down from the tip) to determine specific gravity by the oven-dry weight method--green volume basis using water immersion for volume determination.

RESULTS AND DISCUSSION

Growth

Little height growth occurred during 1970 because unrooted cuttings were planted in late spring and growth ceased in mid-July due to the inherent response of the genotype to the photoperiod in Wisconsin (Larson and Isebrands 1972). However, *Populus* 'Tristis #1' even when well established does not fully utilize the growing season of northern Wisconsin. For example, in 1971 and 1972, 90 percent of the terminal buds were set by the second week in August, several weeks before the first killing frost. Within the *Populus* genus, photoperiod has been considered to be the major factor in determining time of flushing and cessation of growth (Pauley and Perry 1954). However, studies by Dykstra (1974) indicated that annual height growth cessation and photosynthetic rate were also influenced strongly by nitrogen uptake. We believe the later date of growth cessation for 1971 and 1972, when compared to 1970, may be due

² Although the first year was not a full growing season and can be regarded as a year of establishment, after two full growing seasons we consider the trees to be 3 years old. Furthermore, these plots were not a coppice crop; they consisted of only one stem per plant.

to the higher and more constant levels of soil nitrogen being maintained during that period.

Average height growth between spacings was not significantly different until the third year and then the range was from about 10 feet for the highest density to about 12.5 feet for the lowest density (table 1). Significant differences in diameter growth showed up in the second growing season between the 24 by 24 spacings and the narrower spacings. At the end of 3 years the only mortality was in the 9 by 9 plots, which averaged 10 percent loss (fig. 2).

Crown Form

Number of branches, branch lengths, and branch angles were measured to ascertain the effects of competition on crown form at an early age. Although the number of branches did not vary significantly among spacings, branch length did (fig. 3). Differences in branch length between the 9 by 9 and 12 by 12 plots were nonsignificant (averages of 34 in. and 32 in., respectively); however, the 24 by 24 branches were significantly longer (44 in.).

Table 1.--Mean basal diameter and height of 3-yr-old *Populus* 'Tristis #1' grown at three spacings in irrigated and fertilized plots

Spacing (Inches)	Basal diameter			Height		
	1970	1971	1972	1970	1971	1972
	<i>Inches</i>			<i>Feet</i>		
9 by 9	1 ^{0.32a}	0.60a	0.84a	0.90a	5.80a	10.10a
12 by 12	.40a	.69a	.93a	.95a	5.86a	11.10b
24 by 24	.40a	.91b	1.32b	1.14a	6.17a	12.55c

¹ Figures within a column followed by the same letter indicate they are not significantly different at the 95 percent probability level.



Figure 2.--Three-yr-old plot of *Populus* 'Tristis #1' planted at 9 in. by 9 in. spacing.

Branch angles were influenced only at the lower levels of the crown; they were slightly more acute in the 9 by 9 and 12 by 12 spacings. Although figure 3 accurately portrays the branch lengths and branch angles, it should be noted that all long branches on the trees in the plots curve toward the vertical. This allows more leaves to intercept direct sunlight than indicated in the graphs.

Crown closure occurred in all spacings during the second growing season (1971) and by the middle of the third growing season, the lower levels of all plots were very dense (fig. 4).

YIELDS OF COMPONENTS

Dry Weight

The 9 by 9 and 12 by 12 plots produced the equivalent of 16.68 and 14.83 tons/acre, respectively, of above-ground dry matter exclusive of leaves (table 2). Although

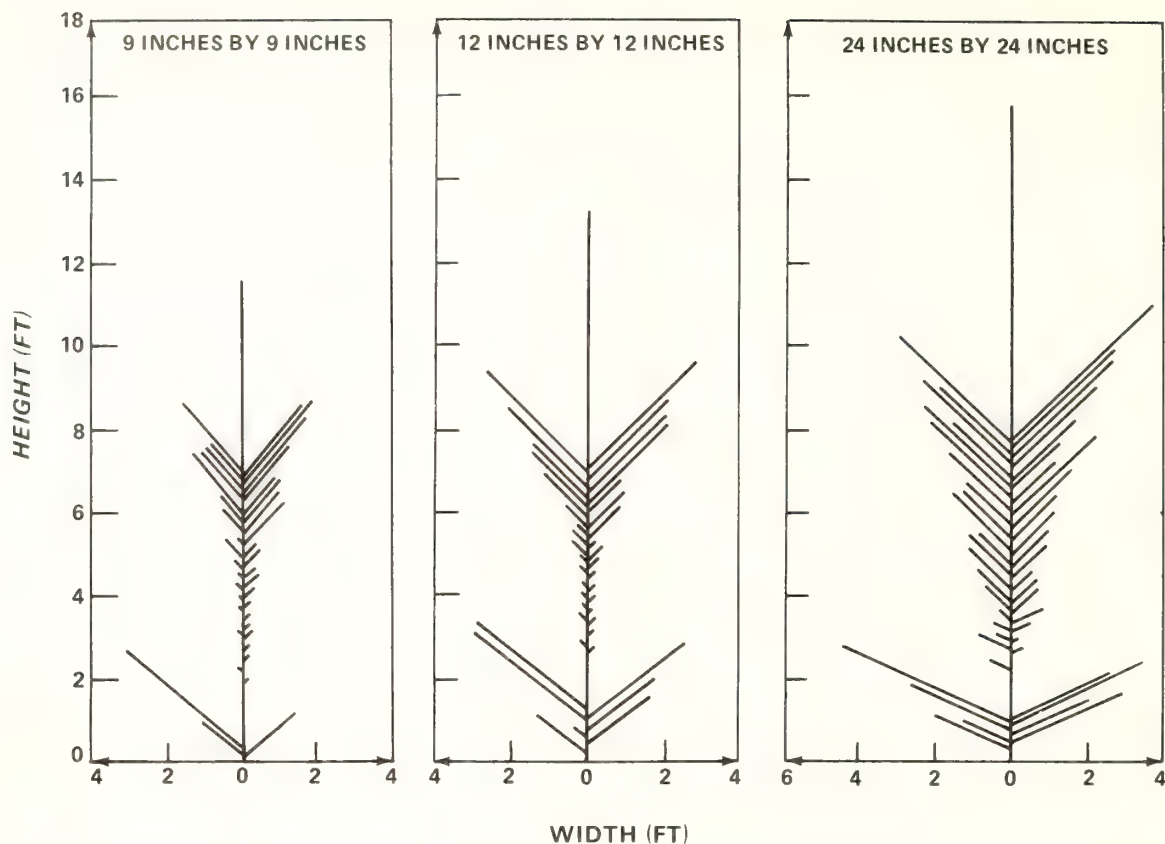


Figure 3.--Crown form of typical 3-yr-old *Populus* 'Tristis # 1'. Trees grown at three spacings in irrigated and fertilized plots.



Figure 4.--Photograph at ground level inside of 24 in. by 24 in. spaced plot showing closed crowns.

these differences are small, they are significant at the 95 percent probability level. The 24 by 24 plots produced only about half as much above-ground dry matter or the equivalent of 7.93 tons/acre.

About 66 percent of the total dry weight yields from plots of all three spacings was wood. Considering the fact that the total dry weight in branches is different between spacings, it is meaningful to note that the percent of total dry weight in wood for all plots was the same (table 3). The above-ground yields (expressed in tons per acre) of wood from both stem and branches, was 11.1 for the 9 by 9 spacing, 9.8 for the 12 by 12 spacing, and 5.3 for the 24 by 24 spacing. Considering that they grew for less than three full growing seasons, it can be assumed that the 9 by 9 plots produced the equivalent of over 4 tons of oven-dried wood per acre per year. These yields tend to corroborate the hypothesis expressed by Gordon and Bentley (1970) that dense stands of narrow-crowned plants with acute branch and leaf angles

Table 2.--Dry weight yields of 3-yr-old *Populus 'Tristis #1'* grown in irrigated and fertilized plots¹

Spacing : (Inches):	Stand density:	Total dry ² : weight	Stem ² : Total:	Wood:	Bark:	Branches ² : Total:	Wood:	Bark:	Tips ³	Dead woody : material
	Trees/acre	Tons/acre	Tons/acre			Tons/acre			Tons/acre	Tons/acre
9 by 9	77,440	16.68	13.31	9.72	3.59	2.97	1.42	1.56	0.27	0.13
12 by 12	43,560	14.83	11.63	8.45	3.18	2.87	1.36	1.50	.25	.10
24 by 24	10,890	7.93	5.77	4.30	1.47	2.02	.99	1.03	.13	.01

¹ Average of three plots, oven dry weight.

² Extrapolated to tons/acre.

³ Top 6 inches of stem.

Table 3.--Total dry weights of components of 3-yr-old *Populus 'Tristis #1'* grown in irrigated and fertilized plots

(In percent)

Spacing : (Inches):	Total tree				Stem	Branches			
	Stem:	Branches:	Tips ¹ :	Deadwood:	Wood:	Bark:	Wood:	Bark:	
9 by 9	80	18	1	1	73	27	47	53	
12 by 12	79	19	1	1	74	26	47	53	
24 by 24	73	25	1	1	74	26	48	52	

¹ Top 6 inches of stem.

will approach maximum photosynthetic production of an area very quickly.

Our extrapolated yields are higher than reported for both natural and planted stands of pure or mixed *Populus*. For example, in this region Einspahr and Benson (1968) calculated the average growth for commercial forest land in the Lake States region to be 22 cubic feet (about 0.25 tons) per acre per year under the "short log" system. Yields are higher when total-tree harvesting systems were employed. Benson and Einspahr (1972) reported yields of 1,900 pounds (0.95 tons) of wood per acre per yr from an 18-yr-old aspen stand in northern Wisconsin. Similarly, Napier (1972) reported about 45 tons dry weight per acre, wood and bark, from a 45 to 50-yr-old aspen-red oak stand in Michigan, or about 1 ton/acre/yr. Furthermore, in the Pacific Northwest mean annual increments in dense thickets of 9 to 14-yr-old red alder were about 5.8 tons of oven-dry stem wood, without bark, per acre (DeBell 1972).

A number of researchers have recently reported yields from dense plantations of intensively cultured hardwoods. For example, Schreiner (1970) reported 2.3 tons/acre/yr

of peeled stem wood from plantations of hybrid poplars in the Northeast at 1 by 4 ft spacings. In Pennsylvania Bowersox and Ward (1968) reported 2.65 tons/acre/yr yields of oven-dry peeled stem wood of 3-yr-old *Populus* grown at 0.5 by 2 ft spacings. Similarly, yields of above-ground material from 3-yr-old sycamore sprouts growing in the Southeast ranged from 3.8 tons/acre/yr in 4 by 4 ft spacing to 7.9 tons/acre/yr in 1 by 4 ft spacing (Saucier *et al.* 1972).

Wood/bark ratios both in stems and branches did not vary significantly between spacings (table 3). In stems there was about three times as much wood as bark, while in the branches there was slightly more bark than wood. This represents a large increase in the wood/bark ratio when compared to the first year results of Larson and Isebrands (1972). Eighty percent of the total dry weight in the 9 by 9 spacing was in the stem in contrast to 73 percent in the 24 by 24 spacing. This difference was significant. Young and Carpenter (1967) also reported 80 percent of dry weight in stems for *Populus tremuloides* from natural stands in similar height classes.

From a utilization standpoint, the percent of total wood in stems versus branches is significant, particularly if branches are less than 1 inch in basal diameter. Furthermore, the quality of pulp produced by small branches is lower than that produced by larger branches and stems (Keays 1971). As the wood content of branches decreases with decreasing diameter, the percent of bark and extractives increase, and the overall yield is lower. Also the costs of chipping and debarking small branches is characteristically high (Keays 1971) because of their small diameter. Hence, it would seem a reasonable management objective to regulate stands to maximize the amount of stem wood.

SPECIFIC GRAVITY

Specific gravity is an index of the amount of cell wall substance in the wood and is often used as a measure of wood quality. In *P. 'Tristis #1'* specific gravity varied considerably by stem position, but not significantly by plant spacing (table 4).

The average specific gravity of the basal portion of the stem, which contains the greatest volume of wood, ranged from 0.377 for the 9 by 9 to 0.403 for the 12 by 12; the 24 by 24 was slightly less at 0.401. At the midpoint of the stem the average specific gravity ranged from 0.353 to 0.361. The lowest average was found three internodes from the tip; although the volume from that point to the tip constitutes less than 1 percent of the total stem. Crist and Dawson (1975) reported that the mean specific gravity of wood from the base, midpoint, and 6 inches from the tip to be 0.402 for 2-yr-old shoots of *Populus 'Tristis #1'*; Larson and Isebrands (1972) reported a similar range in specific gravity in 1-yr-old sprout material from the same clone. Hence, the additional growing season seemed to have no great effect on

specific gravity. Furthermore, it is important to note that high specific gravities at the stem base may reflect a high incidence of tension wood (Isebrands and Parham 1974).

In comparison, Einspahr *et al.* (1972) found specific gravities ranging from 0.277 to 0.340 in a 6-yr-old natural aspen sucker stand. In addition, Pronin (1971) reported specific gravity of cores extracted at breast height of twenty-eight 50-yr-old *Populus tremuloides* or *Populus grandidentata* trees in natural stands in Wisconsin ranged from 0.329 to 0.486. The specific gravity of all samples taken from the base or midpoint in the stem of *Populus 'Tristis #1'* in this study are within the range of these averages. It would appear that the utilization potential of 3-yr-old *P. 'Tristis #1'* grown in irrigated and fertilized stands may compare favorably with native stands of aspen.

SUMMARY AND MANAGEMENT IMPLICATIONS

The results of this preliminary study suggest that more wood can be produced for pulp manufacture under very short rotations and nearly optimal growing conditions than in natural stands.

Trees planted at the closest spacing (9 by 9) produced the most wood--the equivalent of over 4 tons/acre/year. This spacing also produced the largest percent of dry weight in the stem (70 percent).

Average height and diameters were significantly greater in the widest spaced plots (24 by 24).

Competition between plants is effective at a very early age, as evidenced by the variation in average tree size and form. The site appeared to be totally occupied by the *Populus* plants in all the plots by the end of the second growing season.

Table 4.--Specific gravity of fertilized and irrigated 3-yr-old *Populus 'Tristis #1'* shoots at three stem positions

Spacing (Inches)	Three inter- nodes from tip		Midpoint		Basal	
	Average	Range	Average	Range	Average	Range
9 by 9	0.187	0.154-0.211	0.354	0.333-0.383	0.377	0.365-0.387
12 by 12	.193	.167- .214	.361	.341- .395	.403	.377- .404
24 by 24	.166	.133- .200	.353	.341- .357	.401	.380- .421

Specific gravity samples from the basal and middle portions of the trees fell within the range reported for natural stands of aspen.

These results have encouraged us to initiate larger, more comprehensive studies in this region to determine the best combination of clone, spacing, and rotation. Additional research is needed to find the optimum manageable environmental conditions for the combination. Properly oriented research studies could determine not only the biological parameters for intensive culture systems, but economic parameters as well.

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1976. Growth, dry weight yields, and specific gravity of 3-year-old *Populus* grown under intensive culture. USDA For. Serv. Res. Pap. NC-122, 7 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

In a nearly optimal cultural environment, *Populus* 'Tristis #1' grown for 3 years, planted at 9 by 9 inch spacing produced the equivalent of over 4 tons/acre/year of oven-dry wood with specific gravity comparable to native aspen wood. Trees planted at wider spacings yielded less.

OXFORD: 232.43:525.5:812.31:176.1 *Populus* sp. KEY WORDS: spacing-effects, plant-density, short-rotation forestry, maximum yield.

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Seed crops and regeneration problems of



species in Northeastern Wisconsin

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SEED CROPS AND REGENERATION PROBLEMS OF 19 SPECIES IN NORTHEASTERN WISCONSIN

Richard M. Godman and Gilbert A. Mattson

Annual reports were published from 1949 through 1962 to provide the first long-term data on the frequency and size of seed crops for different regions in the Lake States. Although these were discontinued on a regional basis (Rudolf 1963), annual reports have been maintained for 19 species^{1/} on the Argonne Experimental Forest in northeastern Wisconsin for use with natural regeneration studies. Thus we now have a 26-year record for this locality.

The timber stands on the Argonne Experimental Forest are primarily of second-growth seedling origin that have developed following commercial cutting about 1905. Within this glaciated area, the upland topography tends to have well drained silt-loam soils that support a mixture of species having average site indices. Their tree diameters range up to the large saw log size. The lowland topography generally supports the mixed-conifer-swamp types although the jack pine and red pine types are found on the drier, sandy sites. The ratings in table 1 are based on the main canopy trees in these types.

SEED CROP FREQUENCY

As shown in table 2, the most consistent producers were quaking and bigtooth aspen. Both had good or better crops in about 2 of every 3 years. Only three fall-maturing species--American basswood, eastern hemlock, and northern white-cedar--approached this frequency. Good or better seed crops occurred in about 1 out of 2 years in four species--red maple, American elm, balsam fir, and black spruce. All of the remaining 10 species except black ash and red pine produced good or better seed crops about 1 of every 3 years.

Bumper crops occurred in all species except jack pine. Usually, they occurred less frequently than did the good crops except in white spruce, northern white-cedar, American basswood, yellow birch,

and red pine. The most consistent seed producers, the two aspens, each had only one bumper crop.

INTERVAL BETWEEN SEED CROPS

As shown in table 3, good or better seed crops occurred at different intervals in northeastern Wisconsin than those reported by Fowells (1965), U.S. Dep. Agric. (1974), and Wang (1974). These were shorter for 11 species, longer for 5 species, and about the same for 3 species. The greatest differences occurred in the aspens and in black spruce.

As shown in the following tabulation, successive years of good or better seed crops occurred in all species except red pine.

<i>Species</i>	<i>Good or better^{2/}</i>	<i>Poor or fail^{2/}</i>
Spring-maturing species		
Quaking aspen	6	2
Bigtooth aspen	6	2
Red maple	4	5
American elm	3	5
Fall-maturing species		
Hardwoods		
Sugar maple	2	2
Yellow birch	2	3
Paper birch	2	5
American basswood	3	2
White ash	2	4
Black ash	2	7
Northern red oak	3	2
Conifers		
Eastern hemlock	5	2
Balsam fir	3	2
Northern white-cedar	6	2
Eastern white pine	2	3
Red pine	1	2
White spruce	2	3
Black spruce	5	1
Jack pine	7	2

^{1/} Common and scientific names are listed on page 5.

^{2/} Good or better = 61 to 100 percent of full crop; poor or fail = less than 36 percent of full crop.

Table 1.--Yearly ratings^{1/} from 1949 through 1974 for seed crops of 19 tree species in northeastern Wisconsin

Species	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
SPRING-MATURING SPECIES																										
Quaking aspen	--	G	G	G	G	G	G	G	G	G	G	--	G	G	F	F	G	P	P	B	G	G	M-G	F	G	
Bigtooth aspen	--	G	G	G	G	G	G	G	G	G	--	--	M	G	G	F	F	G	P	P	B	G	M-G	F	G	
Red maple	--	M	G	G	G	G	B	--	--	--	M	M	M	G	F	P	P	P	P	B	B	F-P	G	B		
American elm	F	--	M	--	--	--	B	--	--	G	G	M	G	P	G	F	F	F	F	F	B	M	B	P-F	B	
FALL-MATURING SPECIES																										
Hardwoods																										
Sugar maple	F	M	P	G	G	M	M	G	F	G	P	M	P	M	B	F	F	F	G	F	P	B	B	F-P	B	
Yellow birch	F	B	M	P	G	G	P	G	M-G	B	B	F	G	M	G	P	F	F	P	P	P	B	B	F-P	B	
Paper birch	F	B	--	F	G	P	G	--	G	M-G	M	G	M	M	B	F	F	F	P	P	G	G	G	F-P	B	
American basswood	F	G	B	B	P	B	G	P	P	G	B	B	P	P	F	B	B	F	P	P	G	F	B	P-M	B	
White ash	G	G	P	F	F	P	P	P	M-G	B	G	P	F	F	B	B	F	P	P	F	G	F	B	P-F	F	
Black ash	G	B	M	F	F	P	--	C	P	P	M	P	P	P	F	F	G	F	G	P	F	M	P	F-P	F	
Northern red oak 2/	P	P	G	G	--	--	--	--	--	P	P	G	M	M	P	M	P	F	F	B	P	M	P	B	G	
Conifers																										
Eastern hemlock	P	G	P	G	B	P	G	P	--	G-B	M	G	F	G	G	P	P	P	G	M	G	G	G	G-B	G	
Balsam fir	F	B	--	M-G	G	F	G	F	P	G-B	G	G	F	G	P	B	F	F	F	G	F	G	G	F	B	
Northern white-cedar	F	B	M	G	G	M	G	B	P	B	--	--	G	M	G	F	F	B	P	B	G	B	G	G	B	
Eastern white pine2/	P	G	P	P	G	P	P	P	P	M	B	G	F	P	M	M	P	M	G	P	G	B	M	F	G	
Red pine2/	F	M	--	P	P	G	F	F	B	P-F	P	M	F	F	G	M	F	P	M	F	M	P	M	F-P	F	
White spruce	F	B	--	P-M	M	G	G	M	F	P-M	P	B	F	F	B	B	F	F	B	P	P	B	B	P-M	B	
Black spruce	F	B	--	G	M	M	G	M	F	M-G	G	G	F	F	M	P	B	F	G	P	M	G	B	G	G	
Jack pine2/	F	G	M	M-G	M	G	M	P	P	M	P	G	F	M	M	G	F	M	M	G	G	G	G	G	G-B	
1/ B = Bumper, 91-100 percent of a full crop; G = Good, 61-90 percent of a full crop; M = Medium, 36-60 percent of a full crop; P = Poor, 16-35 percent of a full crop; F = Failure, 0-15 percent of a full crop; -- No report.																										
2/ Requires 2 years to mature.																										

^{1/} B = Bumper, 91-100 percent of a full crop; G = Good, 61-90 percent of a full crop; M = Medium, 36-60 percent of a full crop; P = Poor, 16-35 percent of a full crop; F = Failure, 0-15 percent of a full crop; -- No report.

^{2/} Requires 2 years to mature.

Table 2.--Percentage of good or better, medium, and poor annual crops produced by 19 northeastern Wisconsin species for the period 1949-1974

Species	Years Observed	Good+ ^{1/}	Medium	Poor
Spring-maturing species				
Quaking aspen	24	71	8	21
Bigtooth aspen	23	65	13	22
Red maple	21	48	24	28
American elm	20	45	15	40
Fall-maturing species				
Hardwoods				
Sugar maple	26	38	16	46
Yellow birch	26	38	19	43
Paper birch	24	38	16	46
American basswood	26	62	7	31
White ash	26	38	8	54
Black ash	25	28	4	68
Northern red oak ^{2/}	21	38	19	43
Conifers				
Eastern hemlock	25	60	12	28
Balsam fir	25	52	4	44
Northern white-cedar	25	64	16	20
Eastern white pine ^{2/}	26	39	15	46
Red pine ^{2/}	25	16	24	60
White spruce	25	40	12	48
Black spruce	25	52	24	24
Jack pine ^{2/}	26	42	35	23

^{1/} Good+, 61 to 100 percent of full crop; Medium 36-60 percent; Poor, less than 36 percent.

^{2/} Requires 2 years to mature.

The occurrence and duration of repeated crops were most frequent in the aspens, several conifers, and basswood; it was less frequent in other fall-maturing hardwood. The longest period of successive good or better seed crops was 7 years in jack pine, followed by 6 years in both aspens and northern white-cedar, and 5 years in eastern hemlock and black spruce. Consecutive bumper seed crops occurred at least once in eight species; one 3-year period occurred in white-cedar. Three successive 2-year bumper crops occurred in basswood.

All species, except black spruce, had successive years of poor crops or failures. The longest consecutive period was 7 years in black ash followed by 5 years in paper birch, American elm, and red maple and 4 years in white ash. In other species, the duration of poor crops seldom exceeded 2 years. The 5-year period 1965 through 1969 was exceptionally poor for all species.

SILVICULTURAL CONSIDERATIONS

In northeastern Wisconsin, only sugar maple reproduces in abundance on unscarified

Table 3.--*Ranges of good or better seed crops for 19 species in northeastern Wisconsin during the period 1949-1974 as compared with ranges reported for same species in the United States and Canada*
(In years)

Species	:Northeast Wisconsin ^{1/}	:United States ^{2/}	:Canada ^{3/}
Spring-maturing species			
Quaking aspen	1-3(1.4)	4-5	4-5
Bigtooth aspen	1-3(1.5)	4-5	4-5
Red maple	1-6(2.1)	1	2+
American elm	1-6(2.2)	--	1
Fall-maturing species			
Hardwoods			
Sugar maple	1-4(2.6)	2-5	3-7
Yellow birch	1-4(2.6)	1-2	2
Paper birch	1-8(2.7)	1	1-2
American basswood	1-3(1.6)	1	2
White ash	1-6(2.6)	--	3-5
Black ash	1-8(3.6)	--	2
Northern red oak	1-7(2.6)	2-5	2-3+
Conifers			
Eastern hemlock	1-3(1.7)	2-3	2-4
Balsam fir	1-3(1.9)	2-4	2-4
Northern white-cedar	1-3(1.6)	3-5	2-4
Eastern white pine	1-7(2.6)	3-5	3-5
Red pine	3-11(6.2)	3-7	3-7
White spruce	1-5(2.5)	2-6	2-6
Black spruce	1-4(1.9)	4	4-5
Jack pine	1-6(2.4)	3-4	3-4

^{1/} Averages shown in parentheses.

^{2/} As reported by Fowells (1965).

^{3/} As reported by Wang (1974).

seedbeds although good or better crops of other species occur at the same or even greater frequency. The ease of obtaining regeneration of sugar maple can be attributed largely to the rapid development and strength of the radicle of the germinating seed. This radicle is capable of penetrating thick layers of leaves or compacted soils to reach the moist, mineral soil, which is necessary for survival.

In other species--particularly those bearing light seeds--it is doubtful whether appreciable numbers of seeds have conditions favorable for germination on undisturbed seedbeds. Those that do germinate are usually characterized by very slow growth and weak radicles that lack the capability for survival. Therefore, establishment of regeneration in conjunction with planned cuts requires both an adequate seed supply and some degree of site preparation among light-seeded species because of their highly specific seedbed requirements.

The aspens, for example, are prolific seed producers, but the seeds seldom germinate unless the seedbeds are scarified or burned. When the seedbed is burned, aspen

seedlings have been known to comprise 20 to 35 percent of all seedlings after six growing seasons even though the shelterwood overstory had no aspen and all seeds had to blow in from surrounding stands.^{3/}

Other studies of site disturbance from harvesting have shown that few desirable seedbeds are created regardless of the season of logging in the Lake States (Church 1961). Therefore, site preparation required for both the germination and establishment of many species must be coordinated with good seed crops to improve the chances of securing the preferred species. The interval and duration of poor seed crops or failure are often more important than the frequency of good years. Scarified sites, for example, may revegetate to their initial cover in less than 3 years (Godman and Krefting 1960) and the benefits of reduced competition can be lost before a good or better seed crop occurs.

^{3/} Unpublished data on file at the North Central Forest Experiment Station, Northern Hardwoods Laboratory, Marquette, Michigan.

Although the annual record of seed crops provides general guides on the probability of good or better seed years, more reliable estimates of seed crops in fall-maturing species can be made from projections based on the crop size of spring-maturing red maple and American elm (table 4). Based

One of the most consistent fall-maturing seed producers, American basswood, rarely reproduces from seed in many localities regardless of seedbed conditions. Of 7,435 identifiable basswood seeds we found throughout the litter on 72 1-square-foot plots under the crown perimeter of mature

Table 4.--Years between 1949-1974 that fall-maturing species had the same size seed crop as two spring-maturing species (red maple and American elm) in northeastern Wisconsin^{1/}
(In percent)

Fall-maturing species	Spring-maturing species					
	Red maple			American elm		
	Good crop: (10 yrs.)	Medium crop: (5 yrs.)	Poor crop: (6 yrs.)	Good crop: (9 yrs.)	Medium crop: (3 yrs.)	Poor crop: (8 yrs.)
Hardwoods						
Sugar maple	70	40	83	56	33	88
Yellow birch	60	80	83	67	67	75
Paper birch	60	75	100	56	50	88
American basswood	90	80	50	89	67	38
White ash	40	60	83	33	33	50
Black ash	22	40	67	12	67	62
Northern red oak ^{2/}	57	60	50	38	67	62
Conifers						
Eastern hemlock	90	60	33	89	0	38
Balsam fir	70	50	67	89	0	62
Northern white-cedar	90	100	50	89	50	50
Eastern white pine ^{2/}	50	40	50	44	33	38
Red pine ^{2/}	20	50	67	11	50	62
White spruce	60	50	50	56	0	75
Black spruce	80	50	33	78	0	50
Jack pine ^{2/}	70	80	17	56	33	25

^{1/} Based on years both species had reported seed crops.

^{2/} Requires 2 years to mature.

on the years of record now available, seed crop size of the fall-maturing species shows more consistent agreement with red maple than American elm for most hardwoods and conifers. The occurrence of good or better seed crop in red maple indicates that comparable seed crops could be expected from 60 percent to 90 percent of the time for all 1-year fall-maturing species, except white and black ash. The chances are even better for a poor seed crop or failure among fall-maturing species (especially hardwoods) if such occurs the preceding spring in red maple.

The presence of an apparent seed crop, even with site preparation, will not always assure adequate regeneration. In some years, the outer seed coat may develop but few seed may actually form. Germinative capacity is known to vary from tree to tree and from year to year; for many of the preferred species, it is relatively low.

trees in the spring of 1973, only 2 percent were sound.^{3/} All the older seeds that were covered by leaves had rotted and most of the seeds lying on or in the upper leaf layer had been destroyed by rodents. We didn't find any evidence of newly germinated or older seedlings despite the abundance of seed.

Until more specific methods can be developed to assure adequate regeneration of preferred species other than sugar maple at the time they are desired, the most successful approach should be to correlate site preparation with the occurrence of good or better seed crops. The earliest and most reliable predictions of crop size in the 1-year fall-maturing species can be obtained from the size of the crop of the spring-maturing red maple because seed crops occur at irregular intervals for most species.

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COMMON AND SCIENTIFIC NAMES OF SPECIES MENTIONED

Spring-maturing species

Quaking aspen
Bigtooth aspen
Red maple
American elm

Fall-maturing species

Hardwoods

Sugar maple
Yellow birch
Paper birch
American basswood
White ash
Black ash
Northern red oak

Conifers

Eastern hemlock
Balsam fir
Northern white-cedar
Eastern white pine
Red pine
White spruce
Black spruce
Jack pine

Populus tremuloides Michx.
Populus grandidentata Michx.
Acer rubrum L.
Ulmus americana L.

Acer saccharum Marsh.
Betula alleghaniensis Britton
Betula papyrifera Marsh.
Tilia americana L.
Fraxinus americana L.
Fraxinus nigra Marsh.
Quercus rubra L.

Tsuga canadensis (L.) Carr.
Abies balsamea (L.) Mill.
Thuja occidentalis L.
Pinus strobus L.
Pinus resinosa Ait.
Picea glauca (Moench) Voss
Picea mariana (Mill) B.S.P.
Pinus banksiana Lamb.

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1976. Seed crops and regeneration problems of 19 species in northeastern Wisconsin. USDA For. Serv. Res. Pap. NC-123, 5 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Seed crops of 19 species occurred at irregular intervals over a 26-year period but crop sizes of fall-maturing species were related to those of spring-maturing species.

OXFORD: 232.311.1:231.3(775). KEY WORDS: seed crop frequency, seed production, site preparation.

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s would be the major future problems.

WOOD PROCUREMENT PRACTICES and PROBLEMS of ILLINOIS PULPMILLS

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1976

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WOOD PROCUREMENT PRACTICES AND PROBLEMS

OF ILLINOIS PULPMILLS

David C. Baumgartner

The present paper is the first of an intended series to describe pulpwood marketing in Illinois and consider the impacts of possible pulpwood industry expansion on various forestry interests in the State. A 1966 study (Holland, Kallio, and Quigley 1966) showed that wood supplies, water, transportation, and labor resources in the State were favorable for expansion. If expansion occurs, each forestry-related interest group in Illinois would be affected somewhat differently. The intended research series should help minimize the problems that might accompany expansion, so that full potential benefits could be realized.

The purpose of this first paper is to present basic data showing how the pulp and paper industry in Illinois obtains its wood supply, and to document recent changes, future plans, and problem areas in the industry.

STUDY METHODS AND OBJECTIVES

During the summer of 1974 a representative from each woodpulp mill in Illinois was interviewed. The information obtained^{1/}, together with data from earlier studies was used to achieve the following objectives:

1. To obtain current information on the wood purchasing practices of pulpwood users in Illinois including: (a) amount and type of wood purchased, (b) prices paid for wood--the degree of price variations and reasons for them, and (c) wood sources and methods of delivery.
2. To determine future use of pulpwood by Illinois firms.
3. To identify present and future problems of pulpwood-using firms.
4. To assemble data for studies that will help provide a complete picture of pulpwood marketing in Illinois and the Central States region.

^{1/} The interview form is available from the author.

DESCRIPTION OF THE PULPWOOD INDUSTRY IN ILLINOIS

In 1973 the pulping capacity of Illinois' eight woodpulp mills (fig. 1) was 865 tons per day or 57 percent of the total daily capacity of the four Central States of Illinois, Indiana, Iowa, and Missouri (Blyth 1973). Both the number of mills and the pulping capacity has remained stable during the past 20 years. Receipts of pulpwood by Illinois mills have, however, increased steadily in recent years from 90,000 standard cords in 1965 to 193,000 in 1973 (Blyth 1966, 1975). Illinois pulpwood production has also increased from 92,000 standard cords in 1965 to 146,000 in 1973. These increases in production and receipts were due to using more pulpwood and less substitute materials in the pulp mix, and to utilizing a higher percent of pulping capacity (Blyth 1969).

The following tabulation for 1973 shows that Illinois is a net importer of pulpwood even though some wood is exported to other States (Blyth 1975).

	<i>Standard cords</i>
Pulpwood produced in Illinois	145,522
Exported to other States	46,467
Illinois production consumed	
within State	99,055
Imports consumed in Illinois	93,667
Total receipts of Illinois mills	192,722

Missouri was the most important exporter of pulpwood to Illinois; most Illinois exports stayed within the Central States Region or went to adjacent Kentucky.

Wood residues, rather than roundwood or roundwood chips, make up more and more of the wood used by Illinois mills. Residues rose from 24 percent of receipts in 1965 to nearly 64 percent in 1973 (Blyth 1966, 1975).

Seven of the eight Illinois woodpulp mills employ the groundwood or mechanical pulping method and produce roofing felts and insulation materials. Two of these seven also process the felt further into roofing and one produces a wide range of building materials. The 1973 pulping capacity of

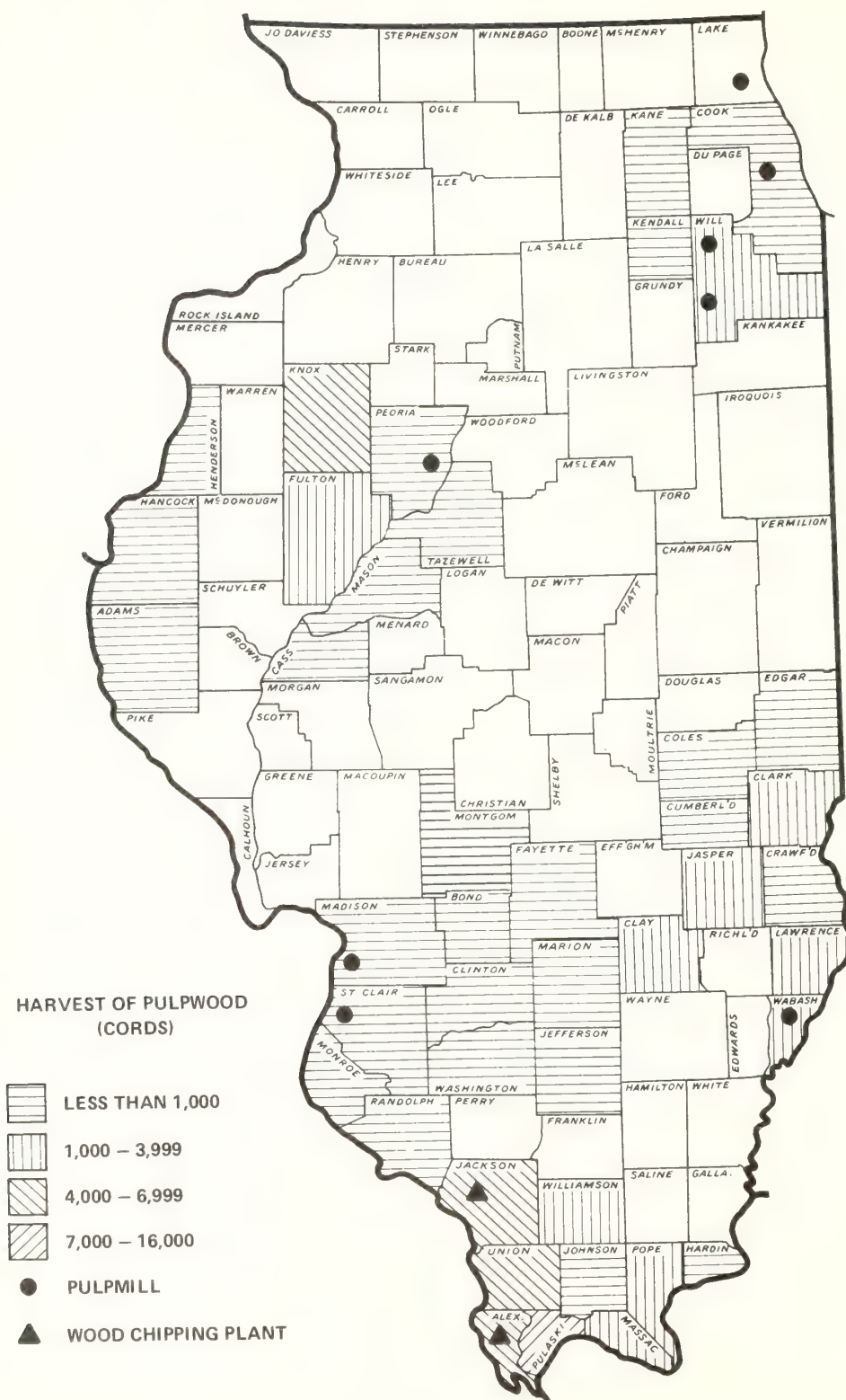


Figure 1.--Location of Illinois pulpmills and wood-chipping plants;
harvest of pulpwood bolts in standard cords by county, 1973.

These groundwood mills ranged from 30 to 100 tons per 24-hour day and averaged about 60 tons per day. One mill with a capacity of 300 tons per day used a semichemical process and produced boxboard. Six of the eight Illinois mills were operating at or near full capacity in 1973; one was operating at 75 percent of capacity, and one at 50 percent. No significant changes in the percent of capacity used, the pulping process, or the materials produced have occurred since 1969.

The percent of wood to wastepaper used in the pulp mix varied from 15 percent to more than 50 percent. Most firms used about 65 percent wood and about 55 percent wastepaper. Very little change in the ratio of wood to paper is possible in the groundwood mills. The single semichemical mill would, however, be capable of using up to 100 percent of either wood or wastepaper in its pulp mix.

All of the Illinois woodpulp mills have been operating at their present locations for more than 50 years and all are owned by parent firms with wood-using plants in other States. Two of the Illinois mills are owned by the same firm. All the mills are located on major water and railways.

In addition to the eight plants that produced woodpulp in Illinois in 1973, there are at least one permanent and several portable or semiportable operations that buy and chip pulpwood for resale to pulping plants. Several pulp and paper mills located in adjacent States also influence the Illinois pulpwood market.

AMOUNT, TYPE, AND SOURCE OF WOOD USED

Of the 193,000 cords of pulpwood used by Illinois pulpmills in 1973, only about 9 percent was purchased as roundwood. Four mills bought and chipped roundwood but only one of these purchased more roundwood than chips. Two other mills maintained chippers that could be used if needed. Purchased chips from wood residues accounted for nearly 64 percent of all pulpwood used and the remaining 17 percent as chips from roundwood. More than 80 percent of all the wood used was hardwoods.

Only about one-third of the pulpwood used in Illinois was handled by an intermediary agent or dealer. The rest was

purchased directly from a roundwood producer or chip-producing plant and normally delivered to the pulpmill by the producer, as none of the Illinois mills purchased any of their own stumpage or did any logging.

As stated earlier, about 99,000 cords, or more than half of the wood used by Illinois pulpmills, was produced within the State.

The pattern of pulpwood production by county clearly indicates that most Illinois pulpwood-using plants operate in a more or less distinct timbershed (fig. 1). Chip production from residue shows a similar county production pattern.

The type and source of the nearly 94,000 cords of wood that were imported by Illinois in 1973 is shown in the following tabulation:

	<i>Total imports (Percent)</i>
Hardwood residue	
from Missouri	36
Softwood residue	
from the Lake States	17
Hardwood roundwood	
from Indiana	10
Hardwood residue	
from the Lake States	7
Softwood residue	
from Iowa	5
Other wood	
from Central and Lake States	17
Miscellaneous wood	
from Mississippi, Tennessee, Alabama, and other States	8
	100

RECEIPT AND INVENTORY PATTERNS

Three of the eight pulpmills in Illinois obtained their wood in equally spaced deliveries throughout the year and had no seasonal pattern of receipts. Two of these operated with residues from a few large, dependable, out-of-State producing plants and the third obtained roundwood and chips through a dependable agent. These firms had very little storage capacity and maintained no more than a few days inventory. The five other firms did experience some seasonal variation in their patterns of wood receipts in 1973 but there was very little uniformity in these patterns, except for a tendency to increase inventories

in early and midwinter followed by a slump in late winter and early spring. Most of the mills said that no typical pattern of receipts could be expected and that weather and local influences often affected receipts unpredictably.

More than 30-days-supply was rare. Inventories were limited both by space and by the firm's ability to use wood before it deteriorated. All the mills would have preferred to have a uniform pattern of receipts and uniformly low inventories if dependable supplies could have been obtained.

PRICES AND TRANSPORTATION METHODS

The average price paid for pulpwood by Illinois mills in 1973 varied from \$9.40 per ton for hardwood roundwood delivered to the mill by a producer, to \$21.00 per ton for softwood roundwood delivered by an agent (table 1). Wood delivered by agents was priced higher than that purchased directly from producers, chips were priced higher than roundwood, and softwood was generally somewhat more expensive than hardwood. The high price of softwood roundwood, however, is partially due to the fact that only a small amount of this material was purchased when local shortages occurred and had to be shipped long distances.

Pulpmills that purchased most of their wood from one or two large, stable, out-of-State firms experienced little or no variation in the price paid for wood in 1973 or recent previous years. Wood obtained from local producers was subject to more price variation and the prices charged by agents

Table 1.--Prices paid for pulpwood by Illinois pulpmills in 1973 by type of wood and marketing agent
(In dollars per ton F.O.B. mill)

Type of wood and marketing agent	Highest: price	Lowest: price	Average: price
Hardwood roundwood from producers	\$10.50	\$ 8.00	\$ 9.40
Hardwood roundwood from agents	22.00	8.50	16.00
Hardwood chips from producers	21.00	8.00	13.64
Softwood roundwood from agents ^{1/}	22.00	20.00	21.00
Softwood chips from producers	21.00	12.00	16.31

^{1/} No softwood roundwood was purchased from producers.

varied widely. Pulpwood prices, generally, increased substantially in early 1974.

Six of the Illinois mills reported high to moderate competition for wood while the other two reported little or no competition. In general the mills that purchased from one, or a few **large**, distant, dependable sources reported little or no **competition** for wood; those buying from numerous local sources faced more.

The price of wastepaper purchased by Illinois mills more than doubled during 1973, averaging about \$18 per ton for mixed paper in early 1973 and rising to an average of \$42 per ton by early 1974. Corrugated paper was much higher in price, sometimes costing twice as much as mixed paper.

Seven of the eight Illinois pulpmills provided transportation data and averaged 70 percent of their wood by truck and 30 percent by rail; all received at least some wood by rail and one obtained all its wood by rail. Even though most of the mills were located on major waterways carrying barge traffic, none had water loading facilities, so no raw material or output from the mills was shipped by water.

The length of the truck haul to Illinois mills varied from 5 to 300 miles. Three of the mills received wood trucked 45 to 50 miles. Two mills had an average truck haul distance of about 100 miles and one did not report its average distance.

The distance wood was shipped by rail ranged from 65 to 600 miles. One mill had an average rail haul of 200 miles, three an average of 350 miles, and three an average between 500 and 600 miles.

CHANGES IN THE ILLINOIS PULPWOOD INDUSTRY

Most Illinois pulpmills noted a definite increase in competition for wood during the period of 1964-1973--particularly in the early 1970's--and they expected further increases. The number of suppliers of roundwood serving the needs of the Illinois mills declined from 139 in 1968 to 120 in 1972 and to only 77 in 1973. The number of chip suppliers, however, increased from 20 in 1968 to 28 in 1972 and to 44 in 1973, obviously paralleling the steady shift from roundwood to residue as a raw material. Further increases in the use of residues are likely because three mills plan to increase

air use of chips and another reported that would like to increase chip use if chips are available. This shift from roundwood residue has been without doubt the most significant development affecting the Illinois pulpwood industry in recent years.

Transportation methods have changed very little in the last 10 years except for slight increase in the percent of wood shipments received by rail.

INDUSTRY CONCERNS

Many pulp mills were concerned with the fact that some sawmills, either currently supplying wood residues or with potential for supplying them, were going out of business. Others felt that sawmills were using smaller logs that previously would have been available for pulpwood. There was general concern that local chip shortages and the exhaustion of local roundwood resources would necessitate transporting wood from more distant points. Competition for local wood from large firms extending their supply radii and capable of influencing local prices was an important concern, particularly for the small mills that were more reliant on local wood suppliers. Two mills also expressed concern over the increasing difficulty in meeting environmental standards.

SUMMARY AND CONCLUSIONS

The number of Illinois pulp mills and plant capacity have remained quite stable during the past 20 years. However, pulpwood production and mill receipts in Illinois have both steadily increased due to an increased proportion of wood in the chip mix and to greater utilization of plant capacity. The sale of Illinois pulpwood to mills in adjacent States has not affected production.

In 1973, about two-thirds of all pulpwood used in Illinois was supplied directly by producers and about one third by an agent who bought from producers. More than 80 percent of all the wood shipped was hardwood. Wood residues accounted for nearly 64 percent of all pulpwood used. Slightly more than half of the pulpwood used was produced within the State and the remainder was imported,

primarily from Missouri, Indiana, and the Lake States.

Receipts and inventories by Illinois pulp mills varied only slightly by season but were subject to unpredictable local influences. Seventy percent of the pulpwood was delivered by truck and the remainder by rail. Most Illinois firms reported a high to moderate degree of competition for wood. Wood prices varied by source and type of wood purchased and with general market factors. Both wood and wastepaper prices increased substantially in late 1973 and 1974.

The most significant change in the Illinois pulpwood industry since 1964 has been the rapid increase in the amount of wood residues used. Paralleling this increase was a decrease in the number of roundwood suppliers and an increase in the number of chip suppliers. Competition for wood increased. Most firms felt that competition and resulting wood price increases would be the major problem of the future.

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Provides current information on the wood-purchasing practices, problems, and future plans of the Illinois pulpwood-using industry.

OXFORD: 721.1:721.3:861(773). KEY WORDS: marketing, pulpwood supply, plant capacity.

Baumgartner, David C.

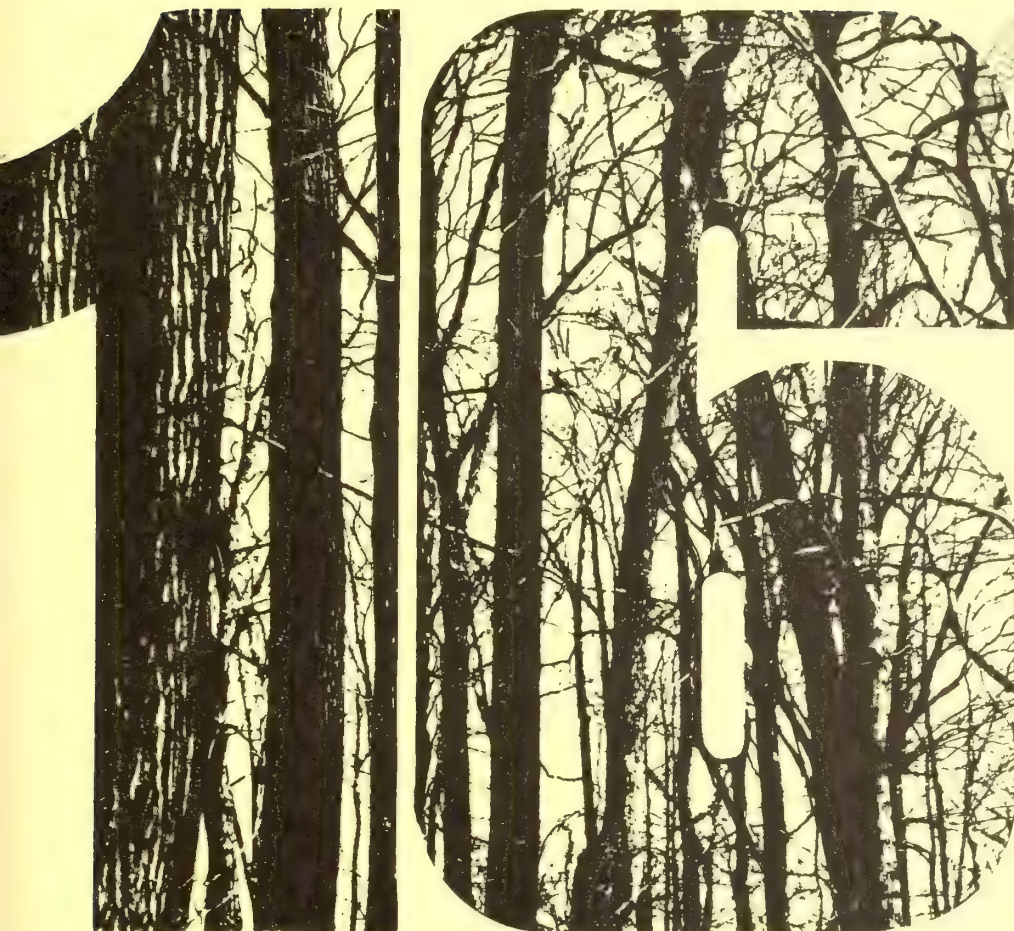
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years

of selection silviculture in upland hardwood stands

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SIXTEEN YEARS OF SELECTION SILVICULTURE IN UPLAND HARDWOOD STANDS

Richard C. Schlesinger

Although selection silviculture changes forest gradually, the cumulative effects over a long period of time may be great. To evaluate such a system, we need to understand both its short-term and long-term effects on particular forest types.

A study of several management systems¹ in upland hardwood stands in southern Illinois showed some short-term changes to fewer cull and low quality trees, fewer small trees, and indications that white oak, hickory, and yellow-poplar are replacing the red oaks as the dominant species.

BACKGROUND

Several variations of uneven-aged management were tested on upland hardwood stands in the Kaskaskia Experimental Forest in southern Illinois. Management units 10 to 30 acres in size were classified into two general productivity groups. The high productivity group (10 mixed hardwood units) is located on northerly slopes and in moist coves (fig. 1 left). The lower productivity group, (11 oak-hickory units)

¹ Study initiated and conducted under the general supervision of Leon S. Minckler.

was confined to the drier ridgetops and southerly slopes (fig. 1 right). Oak site index ranged from 50 to 80.

Initially, the stands contained two to four separate age classes and were only moderately stocked with growing stock trees. The management variations tested included (1) cutting cycles of 4 versus 8 years on the better sites and 8 versus 16 years on the poorer sites, (2) growing the better trees to 20 inches d.b.h. (diameter at 4.5 feet above the ground) versus 25 inches on the better sites and 17 inches versus 22 inches on the poorer sites, and (3) intensive treatment of the uncut portion of the stands (killing unmerchantable trees and weeding the reproduction) versus no treatment. The planned harvest from the mixed hardwood areas was 150 board feet (1/4" International Rule) per acre per year and 75 board feet from the oak-hickory areas.

The silvicultural system applied to all units was a form of small group selection. The merchantable cut was composed of trees above the maximum size objective plus low quality and poor risk smaller



Figure 1.--The photo at the left shows one of the mixed hardwood sites before treatment. The trees have good form and are closely spaced. The photo at the right shows one of the oak-hickory sites before treatment. The trees are generally shorter and of poorer quality.

sawtimber trees. Cull and inoperable² trees were killed following each cutting on the intensive treatment units (all but two units on the mixed hardwood areas and one unit on the oak-hickory areas). Small openings (averaging 1/10 acre) were created for regeneration by cutting groups of trees. During later treatments, an attempt was made to create openings of at least 1/8 acre and to clear the openings of saplings and poles immediately. Pines were planted in the openings following the first harvest on three of the oak-hickory units but this practice was discontinued because survival was poor. Inventories of all trees larger than 4.5 inches d.b.h. were made before each treatment.

The management treatments would not be expected to differentially affect the stands during the 16-year period, and indeed we found no significant differences between treatments. Because the silvicultural system was the same for all management treatments, the data from all units within each productivity group were combined to assess the general changes in the forest.

² Unacceptable growing stock between 5 and 10 inches d.b.h. These trees could have been sold for mine props or pulpwood if a market had existed.

CHANGES AFTER 16 YEARS

The principal changes after 16 years were in the stand structure and in the overall stand quality. In addition, there were strong indications that stand composition will change in the future. The main overstory species, initially and after 16 years were white oak (*Quercus alba* L.), hickory (*Carya* sp.), and the red oaks (*Q. velutina* Lam., *Q. coccinea* Muenchh., and *Q. rubra* L.). Yellow-poplar (*Liriodendron tulipifera* L.) grew on the better sites, and post oak (*Q. stellata* Wangenh.) was found on the oak-hickory areas. The red oak group was the chief component of the stands during the 16 years.

On the mixed hardwood areas, both the number of trees and the total basal area decreased (table 1). The decrease occurred in the smaller sizes; there were 21 fewer trees per acre between 5 and 10 inches d.b.h. The red oak group accounted for almost half the decrease, all in the smaller sizes. This group appears to be essentially an even-aged component of the stands. The average d.b.h. increased from 11.5 to 14 inches, some of the smaller trees grew into sawtimber, replacing the trees that were harvested (table 2), and some mortality occurred. Little, if any, ingrowth into the 5-inch class took place.

Table 1.--Mixed hardwood growing stock

ORIGINAL STAND (TREES PER ACRE)						
D.b.h. (inches):	Hickory:	White: oak :	Red oak : group :	Yellow-: poplar :	Misc.:	Total
5- 7	10.0	8.7	6.1	0.9	3.3	29.0
8-10	5.2	5.6	9.1	1.5	1.9	23.3
11-17	4.5	5.9	15.3	3.1	3.6	32.4
18+	.8	1.2	3.4	.7	.2	6.3
Total	20.5	21.4	33.9	6.2	9.0	91.0
AFTER 16 YEARS (TREES PER ACRE)						
5- 7	6.6	7.6	2.2	1.2	0.8	18.4
8-10	4.1	4.3	3.2	.7	.5	12.8
11-17	4.5	7.9	13.4	2.9	1.3	30.0
18+	.3	1.5	4.8	1.3	.1	8.0
Total	15.5	21.3	23.6	6.1	2.7	69.2
BASAL AREA OF ORIGINAL STAND (SQUARE FEET PER ACRE)						
5- 7	1.9	1.7	1.4	0.2	0.6	5.8
8-10	2.2	2.5	4.1	.7	.8	10.3
11-17	4.4	5.6	15.5	3.0	3.5	32.0
18+	2.0	2.5	7.1	2.2	.6	14.4
Total	10.5	12.3	28.1	6.1	5.5	62.5
BASAL AREA AFTER 16 YEARS (SQUARE FEET PER ACRE)						
5- 7	1.3	1.4	0.5	0.2	0.1	3.5
8-10	1.8	1.9	1.4	.3	.2	5.6
11-17	4.3	8.1	14.5	3.3	1.3	31.5
18+	.5	3.3	10.6	2.8	.2	17.4
Total	7.9	14.7	27.0	6.6	1.8	58.0

Table 2.--Trees removed between the first and last inventories
(In number per acre)

MIXED HARDWOOD SITE							
Category	D.b.h. :(inches)	Hickory	White: oak	Red oak: group	Yellow- poplar	Misc.	Total
Inoperable	5- 7	3.6	2.5	1.6	0.3	2.7	10.7
	8-10	1.7	1.4	1.7	.3	1.7	6.8
Merchantable	11-17	1.0	.6	2.5	0.3	1.8	6.2
	18+	.9	.8	2.7	.6	.3	5.3
Cull	5- 7	5.4	4.5	2.1	0.5	11.7	24.2
	8-10	1.0	.7	1.0	.3	2.8	5.8
	11-17	1.1	.4	1.5	.2	2.0	5.2
	18+	.2	.2	.3	.1	.1	.9
Total		14.9	11.1	13.4	2.6	23.1	65.1
OAK-HICKORY SITE							
Inoperable	5- 7	2.8	1.7	1.9	0.8	0.9	8.1
	8-10	1.7	1.0	1.7	.5	.5	5.4
Merchantable	11-17	1.2	.6	2.5	.4	.2	4.9
	18+	.4	.5	1.9	.1	.1	3.0
Cull	5- 7	4.9	2.5	3.3	1.3	4.7	16.7
	8-10	1.2	.6	1.3	.4	.9	4.4
	11-17	1.3	.6	1.7	.4	.7	4.7
	18+	.1	.2	.6	.2	.1	1.2
Total		13.6	7.7	14.9	4.1	8.1	48.4

The other half of the decrease is accounted for by the hickories and miscellaneous species. From a management standpoint, these species were considered least desirable and therefore were cut heavier than the oaks and yellow-poplar. For these species also, most of the decrease is in the number of small trees.

Both white oak and yellow-poplar had the same number of trees after 16 years as were initially present. Ingrowth was adequate to replace trees removed by cutting or mortality. Yellow-poplar is the only species to have more 5- to 7-inch trees. During logging, an attempt was made to scarify the openings created, and this practice combined with some release and weeding was sufficient to regenerate the central portion of the larger openings to yellow-poplar. Ingrowth trees of the more tolerant, persistent white oak were already present in the stands at the start of the study as saplings.

On the less frequently treated oak-hickory areas, both the number of trees and the basal area increased (table 3), but there was a slight decrease in the number of small trees. The red oak and miscellaneous groups contained fewer trees after 16 years, post oak had the same amount, and white oak and the hickories increased because of ingrowth. On these areas also, there are fewer 5- to 10-inch red oaks; the average diameter of the group increased from 10 to 11 inches.

A managed, uneven-aged stand is characterized by fewer trees in each successively larger diameter class. This structure allows for natural mortality, selection of the better trees to retain for future growth, and the generally slower growth rates of subdominant trees, while providing for the replacement of the trees that are removed by cutting or that grow into the next higher diameter class. The diameter distribution on the mixed hardwood areas, however, has deviated from this structure--(fig. 2), there are too few trees in the smaller diameter classes. The oak-hickory areas, on the other hand, have enough small trees (fig. 3), but a deficit may be developing in the middle diameter classes.

One problem in bringing a stand under management is developing a sustainable stand structure. During the long transition from unmanaged to managed conditions the diameter distribution may little resemble the usual one for the silvicultural system. In our stands a relatively even-aged red oak group is moving through the stand so the transition period will include the time necessary for this movement to be completed and for this group to be replaced. The stand structure after 16 years indicates that the transition period, particularly for the mixed hardwood areas, is not over.

Stand quality, as measured by the relative number of cull and inoperable trees, improved on both the mixed hardwood and the oak-hickory areas (table 4). Excluding the

Table 3.--Oak-hickory growing stock

ORIGINAL STAND (TREES PER ACRE)						
D.b.h. (inches)	Hickory	White oak	Red oak	Post oak	Misc.	Total
5- 7	10.2	9.9	12.0	3.4	1.9	37.4
8-10	3.6	6.4	10.7	1.8	.7	23.2
11-17	3.6	5.3	12.6	1.2	.9	23.6
18+	.4	.6	2.3	.1	.2	3.6
Total	17.8	22.2	37.6	6.5	3.7	87.8
AFTER 16 YEARS (TREES PER ACRE)						
5- 7	11.5	13.2	9.7	2.8	1.4	38.6
8-10	4.3	6.7	7.6	1.8	.5	20.9
11-17	3.2	8.8	14.8	1.7	.7	29.2
18+	.0	.8	2.6	.1	.1	3.6
Total	19.0	29.5	34.7	6.4	2.7	92.3
BASAL AREA OF ORIGINAL STAND (SQUARE FEET PER ACRE)						
5- 7	1.9	2.0	2.5	0.7	0.3	7.4
8-10	1.6	2.8	4.6	.8	.3	10.1
11-17	3.6	5.0	12.4	1.1	.9	23.0
18+	.8	1.3	4.8	.3	.3	7.5
Total	7.9	11.1	24.3	2.9	1.8	48.0
BASAL AREA AFTER 16 YEARS (SQUARE FEET PER ACRE)						
5- 7	2.1	2.5	1.9	0.6	0.2	7.3
8-10	1.8	2.9	3.4	.8	.2	9.1
11-17	3.0	8.6	15.2	1.6	.7	29.1
18+	.3	1.8	5.7	.0	.4	8.2
Total	7.2	15.8	26.2	3.0	1.5	53.7

three units on which cull removal was not part of the treatment, there were only 14 percent as many cull and inoperable trees on the mixed hardwood areas and 37 percent as many on the oak-hickory areas. This improvement in stand quality obviously resulted from the removal of the poorer trees rather than an increase in the number of better trees. On the intensively treated areas, it was necessary to kill 54 trees per

acre on the mixed hardwood areas and 41 on the oak-hickory areas. More than 60 percent of the trees killed were in the 5- to 7-inch d.b.h. class. On the three units that had no treatment, the number of cull and inoperable trees declined by 10 percent during the management period, indicating that many of the smaller cull and inoperable trees died naturally or developed into acceptable growing stock.

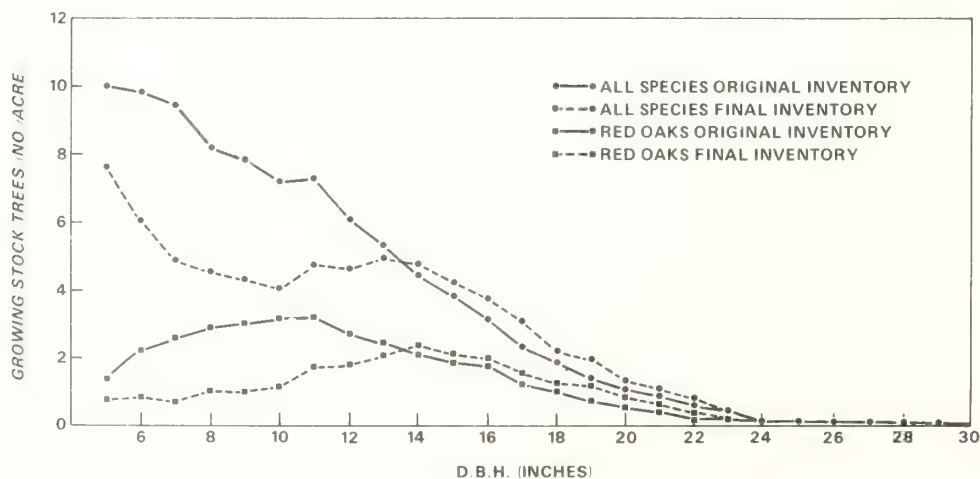


Figure 2.--Diameter distribution on the mixed hardwood sites.

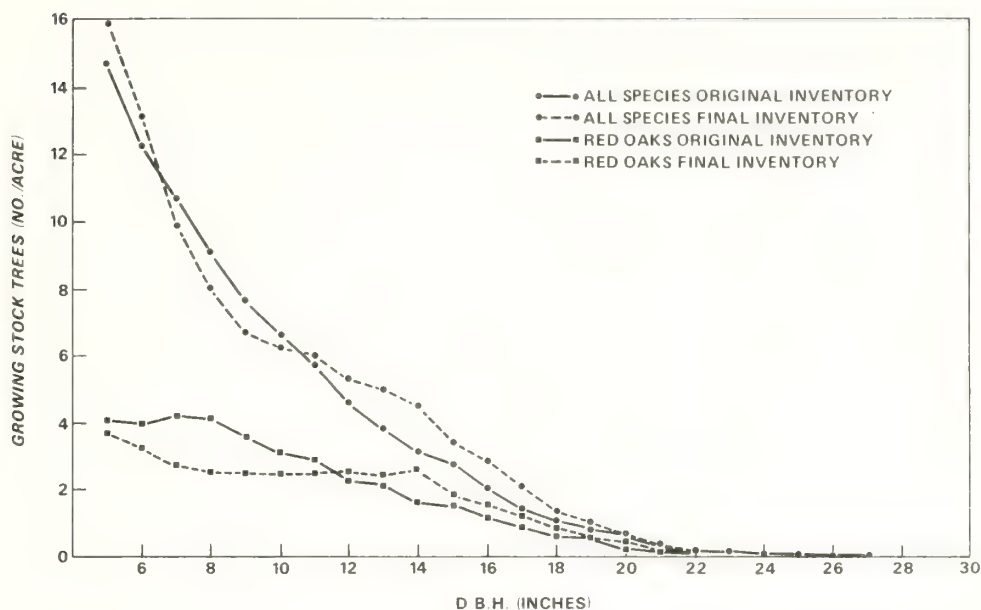


Figure 3.--Diameter distribution on the oak-hickory sites.

The merchantable volume increased by 1,100 board feet per acre on both the mixed hardwood and oak-hickory sites (tables 5 and 6). The increase for the red oak group alone amounted to 800 and 730 board feet, respectively. The growth per acre per year (increase in standing volume plus harvested volume) averaged 218 board feet and 133 board feet, respectively; the red oak group was the dominant factor. On both areas, the average volume per tree increased, as did the average diameter of the sawtimber, reflecting the maturing of the red oak group.

CONCLUSIONS

Because the stands were not fully stocked initially, changes in stand characteristics would have been expected during the 16-year period even without management as the stands continued their recovery from past disturbances. The timber volumes harvested during the period were 149 board feet per year on the mixed hardwood areas (almost exactly as planned) and 64 board feet per year on the oak-hickory areas, about 15 percent below the desired harvest. Growth added 69 board feet per year to the standing volume on both areas. However, because a large portion of this growth and yield was derived from the red oak group, and this group does not appear to be replacing itself, these figures may not be good indicators of future growth and yield.

Table 4.--Cull and inoperable trees (per acre basis, intensively treated units only)

MIXED HARDWOOD						
Category	Hickory	White oak	Red oak group	Yellow-poplar	Misc.	Total
Number of Trees						
Original	4.1	3.0	3.4	0.6	13.2	24.3
After 16 years	.9	.7	.4	.2	1.2	3.4
Basal Area						
Original	1.9	1.3	2.1	0.4	4.6	10.3
After 16 years	.3	.4	.3	.1	.3	1.4
OAK-HICKORY						
Number of Trees						
Original	6.4	3.3	5.4	1.8	4.8	21.7
After 16 years	2.5	1.5	1.9	.6	1.6	8.1
Basal Area						
Original	2.6	1.7	3.2	1.0	1.6	10.1
After 16 years	.7	.4	1.0	.2	.3	2.6

If the management is continued, the most likely species to replace the red oak group are white oak, hickory, and, on the better sites, yellow-poplar. The yellow-poplar regeneration, where present, provides ample opportunity for normal crop tree selection. Just what proportion of the white oak and hickory saplings, some of which may be as old as the overstory, will respond to management and develop into acceptable crop trees is yet an open question. And continued cultural treatments

Table 5.--*Mixed hardwood volume*
(In board feet per acre)

ORIGINAL STAND						
D.b.h. (inches):	Hickory:	White: oak	Red oak: group	Yellow: poplar:	Misc.:	Total
11-17	446	430	1,423	330	294	2,923
18+	291	250	852	341	74	1,808
Total	737	680	2,275	671	368	4,731
AFTER 16 YEARS						
11-17	485	763	1,603	422	132	3,405
18+	99	383	1,474	460	19	2,435
Total	584	1,146	3,077	882	151	5,840
GROWTH AND YIELD						
Total harvested	365	242	1,183	368	221	2,379
Total growth	212	708	1,986	579	4	3,488
Growth/year	13	44	124	36	1	218

Table 6.--*Oak-hickory volume*
(In board feet per acre)

ORIGINAL STAND						
D.b.h. (inches):	Hickory:	White: oak	Red oak: group	Post: oak:	Misc.:	Total
11-17	279	361	1,095	61	77	1,873
18+	86	125	534	23	47	815
Total	365	486	1,629	84	124	2,688
AFTER 16 YEARS						
11-17	242	727	1,577	95	74	2,715
18+	33	191	781	10	66	1,081
Total	275	918	2,358	105	140	3,796
GROWTH AND YIELD						
Total harvested	170	126	645	33	49	1,023
Total growth	80	558	1,374	54	65	2,131
Growth/year	5	35	86	3	4	133

may be necessary to restrain the more tolerant but less desirable species such as American hornbeam (*Carpinus caroliniana* Walt.) and Florida maple (*Acer barbatum* Michx.).

Any conclusions based on a portion of the transitional period from unmanaged to managed conditions must be considered

tentative. Nevertheless, many stands are being placed under management for the first time. Although the specific reaction to group-selection silviculture will be influenced by the initial stand structure and condition, the types of changes that have occurred in these upland hardwood stands can be expected to occur in other upland hardwood stands.

Schlesinger, Richard C.

1976. Sixteen years of selection silviculture in upland hardwood stands. USDA For. Serv. Res. Pap. NC-125, 6 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Describes the changes in the structure and quality of two upland central hardwood areas and discusses an anticipated change in species composition.

OXFORD: 228:221.411:176.1(773). KEY WORDS: uneven-aged management, silvicultural systems, group selection.

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EIGHT-YEAR performance of interplanted hardwoods in southern WISCONSIN oak clearcuts BY PAUL S. JOHNSON



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CONTENTS

Methods	1
Results	2
Discussion	4
Literature Cited	6
Appendix I.--Derivation of Topographic Site Coefficients	7
Appendix II.--Equations for Predicting Heights from Field Growing Seasons and Site	7
Appendix III.--Regression Equations for Height Attainment Probabilities Estimated from Age	8
Appendix IV.--Derivation of Planting Factors	8

EIGHT-YEAR PERFORMANCE OF INTERPLANTED HARDWOODS IN SOUTHERN WISCONSIN OAK CLEARCUTS

Paul S. Johnson

Interplanting is defined as "setting young trees among existing forest growth, planted or natural" (Ford-Robertson 1971). Thus, interplanted trees usually develop in competition with other natural woody vegetation that is continually changing because of growth and mortality. These compositional and structural changes occur relatively rapidly in hardwood clearcuts. Thus, the performance of trees interplanted in such clearcuts can be evaluated in relation to the growth of dominant competing vegetation, such as stump sprouts. To facilitate this evaluation, I used data from a study on northern red oak (*Quercus rubra* L.) stump sprout growth (Johnson 1975) to define success criterion for interplanted trees because oak stump sprouts often predominate in oak clearcuts. The present study was conducted in two 20-acre clearcuts in upland forests of Wisconsin, one on the Coulee Experimental Forest near La Crosse and the second near Albany south of Madison. On both areas, interplantings were made the spring following dormant season cutting of all trees 2 inches d.b.h. and larger. Site conditions and planting methods are detailed in Johnson (1971).

METHODS

I arbitrarily defined two criteria for judging the relative position and competitive status of interplanted trees: one assumes that trees must be at least 80 percent of the average height of red oak stump sprouts growing on a site; the second that a tree must be at least 60 percent of the height of a red oak stump sprout. The second might suffice, for example, where stump sprouting has been controlled with herbicides or where early silvicultural cleanings are planned.

To account for variation in tree height attributable to site, the minimum limits of height for these relative height criteria (RH60, RH80) were adjusted using a measure of site quality called the topographic site coefficient (Appendix I). This provided the range of site-dependent minimum heights

shown in figure 1. Using the RH80 criterion, for example, a planted tree after 8 years on the best site observed in the study areas would have to be at least 14.6 feet tall to be successful but would have to be only 12.3 feet tall on the poorest site. Using the RH60 criterion, planted trees after 8 years on the best sites would have to be at least 10.9 feet tall, but only 9.2 feet on the poorest site.

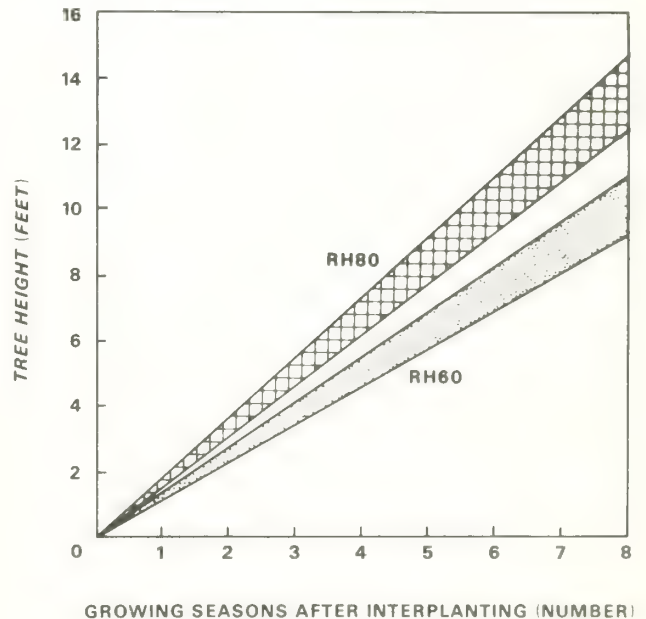


Figure 1.--Tree height in relation to number of growing seasons after interplanting for the range of minimum limits for relative heights (RH) 60 and 80. (Minimum limits for relative heights vary because of adjustments for variation in site. Thus, the lowest values (lower edge) of each relative height class are minimum tree heights on the poorest sites encountered in study plots; uppermost values (topside edge) are minimum tree heights on the best sites. Equations for height estimates are given in Appendix II.)

RESULTS

Survival, Height and Success

Among the six species planted at Albany, survival ranged from 49 percent for northern red oak to 94 percent for white ash (*Fraxinus americana* L.) (as shown in table 1). Mean height was greatest for yellow-poplar (*Liriodendron tulipifera* L.) (14.8 feet), but red maple (*Acer rubrum* L.), sugar maple (*A. saccharum* Marsh.), and white ash all averaged between 12 and 13 feet. Based on the RH80 criterion, sugar maple and red maple were the most successful; white ash and yellow-poplar were only 6 to 7 percent less successful than the maples. Based on the RH60 criterion, white ash was the most successful species. American basswood (*Tilia americana* L.) and northern red oak were the least successful and also the most varied in survivor height. Although the northern red oaks had been relatively large (they averaged 20.7 inches at time of planting) only one out of four attained RH60 after 8 years.

Survival among the four species planted at Coulee was similar to that at Albany. The range was from 60 percent for northern red oak to 95 percent for white ash. Mean height was greatest for yellow-poplar, although it was nearly as tall for white ash and sugar maple. Based on the RH80 criterion, sugar maple and yellow-poplar were almost equally successful. Although the mean height of white ash at the time of planting was greatest and least variable of all trees planted, the success percentage for white ash based on attaining RH80 was only 8.9 percent. However, based on the RH60 criterion, white ash ranked second to sugar maple. Red oak showed the lowest success and greatest variation in survivor height.

Development of trees was also expressed as the probability of individual trees attaining RH60 or RH80 in relation to the number of growing seasons after interplanting. This was done by regression analysis (Appendix III). Three types of probability trends are evident in the data from the Albany plots shown in figure 2. In one type, American basswood and northern red oak decline very rapidly to a plateau of relatively low probabilities: their estimates were below 0.2 by the second or third growing season using the RH80 success criterion. For the same success criterion, probabilities for red and sugar

Table 1.--Height, survival, and success of interplanted hardwoods

Species	ALBANY TRANSPLANTS									
	Height when planted					Eighth year				
	Mean		Coefficient of variation		Standard deviation	Height of survivors		Survival	Planting success ¹	
	(In.)	(In.)	(Percent)	(Ft.)		Mean	Standard deviation		when success criteria is relative height ²	is relative height ²
									60	80
Northern red oak	20.7	7.1	34.5	9.4	5.3		56.0	49	25.3	11.6
Yellow-poplar	16.8	5.4	32.3	14.8	5.8		39.3	60	44.8	36.4
Sugar maple	10.9	3.6	33.2	12.1	5.9		48.8	79	52.1	42.5
White ash	27.2	6.2	22.8	12.4	3.8		30.8	94	70.2	35.5
American basswood	10.6	3.6	34.0	6.0	4.1		68.9	54	7.6	2.2
Red maple	10.5	4.0	37.9	12.9	5.1		39.8	80	54.5	42.0
COULEE SEEDLINGS										
Northern red oak	6.7	2.8	41.8	6.0	3.6		59.5	60	6.0	0.5
White ash	18.0	3.9	21.8	9.4	3.8		40.3	95	34.6	8.9
Sugar maple	6.5	2.2	33.7	9.6	4.7		49.1	88	40.2	14.9
Yellow-poplar	5.5	2.3	42.4	10.0	5.0		50.1	68	31.0	15.5

¹Planting success is the percent of planted trees surviving and reaching a given relative height after eight field growing seasons.

²Relative height is the average height (adjusted for site) of northern red oak stump sprouts at age 8 that provides the relative height standard of 100; thus a planted tree with a relative height of 80 would be 80 percent of the expected height of a red oak stump sprout growing on a similar site.

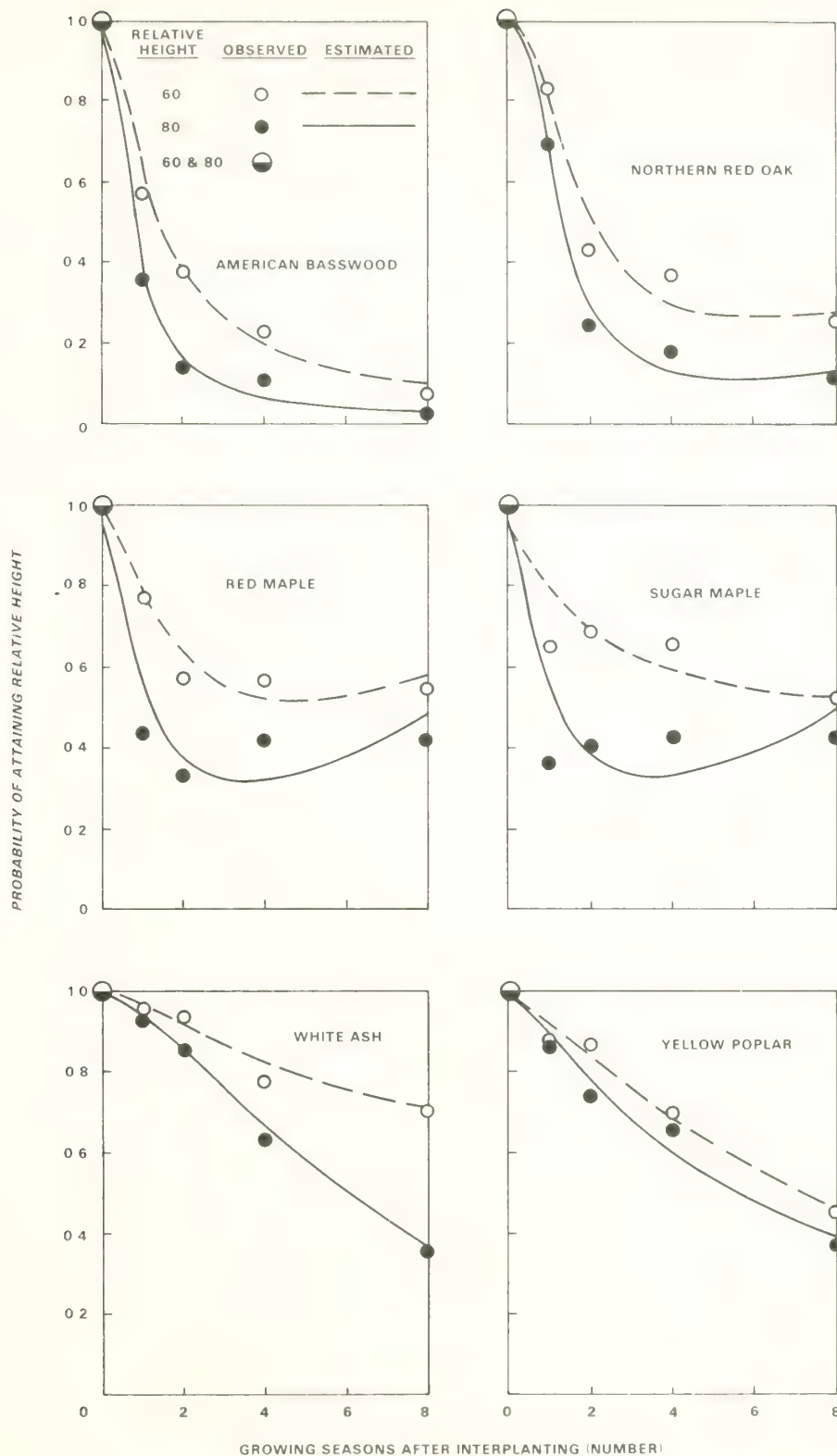


Figure 2.--Probabilities of interplanted trees attaining relative heights 60 and 80 based on 1-1 transplants interplanted at Albany. (Equations for regression estimates are given in Appendix III.)

maples also declined rapidly, dropping to near 0.3 by the fourth growing season. After four growing seasons, however, there were modest but statistically significant increases in probabilities to an eighth-year estimate approaching 0.5. White ash and yellow-poplar formed a third trend, exhibiting a relatively slow and nearly linear decline for both success criteria, and decreasing to near 0.4 for the RH80 criterion at 8 years.

All four species on the Coulee plots declined to low probabilities (<0.2) by the fourth growing season for both success criteria (fig. 3). All species exhibited some rebounding to higher values after the fifth growing season. Nevertheless, all estimates for the eighth growing season were less than 0.2 for the RH80 criterion. In contrast, based on the RH60 criterion, probabilities for all species except red oak increased to levels between 0.34 and 0.46 by the end of the eighth field growing season.

Application of Results

Even though the two study areas represent case studies, results might be applied to interplantings where quality and vegetative condition of the planting site, and size and condition of the planting stock are similar to those tested. Different seed sources, extremes in weather, and improper care and handling of stock may cause significant departures from test results. The results for yellow-poplar should be interpreted cautiously because the study areas are outside the natural range of this species.

The number of trees that must be planted to ensure at least one "successful" tree after the eighth field growing season (with probability of 0.8) is shown in table 2. Termed "planting factors," these are based on the estimated probabilities shown in figures 2 and 3; how they were derived is explained in Appendix IV.

For example, based on table 2, if a tree planter wanted to be reasonably assured of having at least 200 interplanted sugar maples per acre attain RH80 after 8 field growing seasons, he would plant 500 trees (2.5×200) per acre of the large nursery stock or 1,960 trees (9.8×200) of the small nursery stock. If he used the RH60 success criterion, only 440 of the large-size or 520 of the small-size trees would have to be planted per acre. However, if the RH60 criterion was acceptable and the

only objective was to plant a minimum number of trees, the large white ash planting stock (planting factor = 1.3) would be the best choice among the alternatives presented.

Although nursery stock is usually catalogued according to age (e.g., 1-0, 2-0, etc.), size of stock within the same age classification can vary greatly between nurseries, years, and seed sources. Thus, size (as in table 2) rather than age should be the basis for judging quality of planting stock (Limstrom 1963).

DISCUSSION

Height attainment probabilities are a combined expression of mortality and relative height growth. Growth and mortality are determined by various factors including seedling size, physiological condition, and shade tolerance, together with site quality, competition, and cultural measures used during or after interplanting.

If decreasing probabilities in figures 2 and 3 are attributable primarily to slow growth, the curves can potentially change direction with time, depending on rates of height growth. This is apparent in the red and sugar maple curves for Albany, and in the curves for all species for Coulee, where interplanted trees showed slight to moderate increases in height attainment probabilities after the fourth growing season. Where small planting stock was used, such rebounding may be attributable to a requirement for a relatively long establishment period before substantial height growth begins. Seedling shade tolerance may also be a factor. However, regardless of the cause, continued increases in height attainment probabilities are possible, and the planting factors associated with rebounding curves may be somewhat high in relation to future stocking needs.

Silvicultural cleanings and other cultural techniques can also modify growth rates and survival, which would alter success probabilities in young hardwoods. For example, moderate thinning in 7- to 9-year-old stands in Ohio significantly increased height growth of yellow-poplar and northern red oak saplings (Allen and Marquis 1970). However, it may be more practical to prevent or limit unwanted competition using herbicides immediately after clearcutting than to later thin sapling stands.

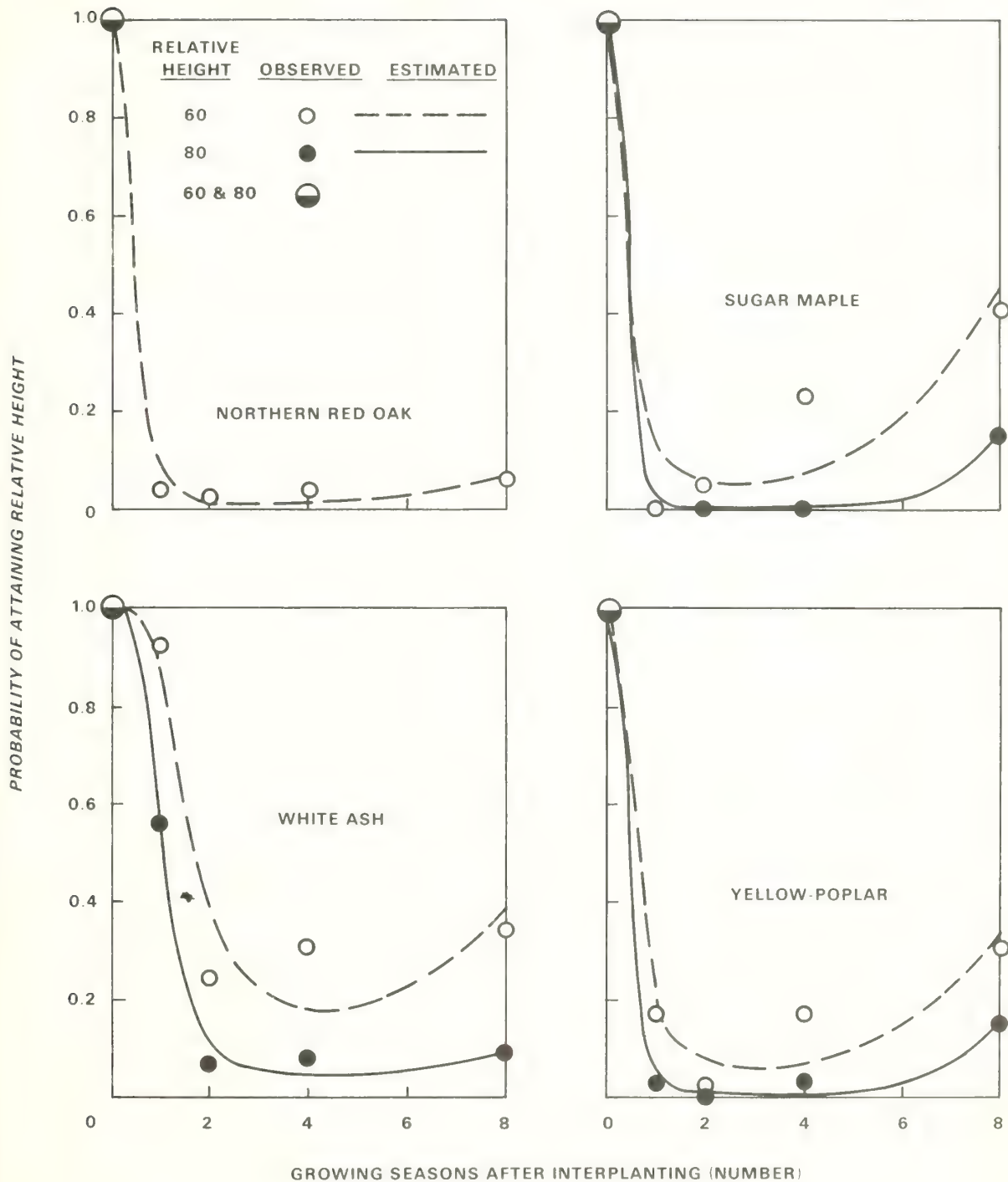


Figure 3.--Probabilities of interplanted trees attaining relative heights of 60 and 80 based on 1-0 seedlings interplanted at Coulee. (Equations for regression estimates are given in Appendix III.)

Table 2.--Planting factors¹ for two eighth-year success criteria by species and size of planting stock

Species	Top length : of planting stock		Planting factor : when success criteria : is relative height ²	
	Mean	Range	80	60
	(In.)	(In.)		
Northern red oak	21	14-28	11.4	5.1
	7	4-10	(³)	21.3
Yellow-poplar	17	11-22	3.4	2.7
	5	3-8	9.1	3.9
Sugar maple	11	7-14	2.5	2.2
	6	4-9	9.8	2.6
White ash	27	21-33	3.5	1.3
	18	14-22	15.5	3.4
Red maple	10	6-14	2.6	1.9
American basswood	11	7-14	51.2	16.2

¹Planting factor is the number of planted trees required to produce, with a probability of 0.80 or greater, at least one "successful" tree at the end of the eighth field growing season. Assumes that shoot/root ratios of planting stock are well balanced and that stock is planted on sites similar to study areas.

²Relative height is the average height (adjusted for site) of northern red oak stump sprouts at age 8 that provides the relative height standard value of 100. Thus, a planted tree with a relative height of 80 would be 80 percent of the expected height of a red oak stump sprout growing on a similar site.

³Probability of success is too small to provide meaningful planting factor.

Herbicides should be applied before interplanting to avoid possible damage to planted trees. Where there are large numbers of small elms (*Ulmus* spp.), black cherry (*Prunus serotina* Ehrh.), boxelder (*Acer negundo* L.), and eastern hophornbeam (*Ostrya virginiana* Mill. (K. Koch)), herbicides should be applied immediately after cutting. Stumps of these species produce dense, rapidly growing sprout clumps that can overtop interplantings during the first 20 years of stand development. Where there is potential for the development of less than 50 to 60 stump sprout clumps of desirable species (e.g., oaks and basswood) per acre, interplantings may be compatible with coppice. However, where stump sprouts are expected to exceed 30 to 40 clumps per acre, I recommend using the RH80 success criteria in calculating stocking needs.

The development of guidelines for evaluating the potential of advance natural reproduction and stump sprouting¹ could

¹Ivan L. Sander, Paul S. Johnson, and Richard F. Watt. 1975. A guide for evaluating the adequacy of oak advance reproduction. Unpublished manuscript on file at the North Central Forest Experiment Station, Columbia, Missouri.

provide an objective basis for determining required numbers of supplemental interplanted trees. However, longer term interplanting studies will be needed to determine the potential contribution of interplantings to future stocking needs because measures of stocking (e.g., Roach and Gingrich 1968) are usually not practical until stands are 15 to 20 years old.

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	a	b
Lower slopes	0.0725	0.0965
Middle slopes	.0325	.0945
Upper slopes	.0400	.0820

SMI is then weighted by soil depth to produce a measure of site quality. For convenience, these weighted indices are re-scaled to a 0.1 (poorest site) to 1.0 (best site) value range, and termed "topographic site coefficients" (TSC). The final relation, where soil plus parent material depth is in inches (within a depth range of 10 to 50 inches), can be expressed:

$$\text{TSC} = (\text{SMI}) (\text{soil+parent material depth}) \\ 0.05332 + 0.04395.$$

APPENDIX I.--

DERIVATION OF TOPOGRAPHIC SITE COEFFICIENTS

A topographic site coefficient is a measure of site quality based on soil plus parent material depth to bedrock (to a maximum depth of 50 inches) weighted by an index of average growing season soil moisture associated with slope position and aspect (azimuth). Its derivation is based on the azimuth transformation (A_t):

$$A_t = \cos(\text{azimuth} - 45^\circ) + 2.$$

This transformation yields values from 1 (southwest facing slopes) to 3 (northeast facing slopes). Southeast and northwest slopes have values of 2, which is also the value assigned to level topography and all slopes less than 15 percent.

Base values for soil moisture indices were derived from measurements made by Stoeckeler and Curtis (1960) for a southern Wisconsin oak stand occupying north and south aspects. Soil moisture measurements on three slope positions (upper, middle, and lower thirds) within each aspect provided paired points for constructing three linear relations between soil moisture index (SMI) and transformed azimuth (A_t). For each slope position, the relation can be expressed by the following equation:

$$\text{SMI} = a + b(A_t),$$

for which the following values of a and b were derived:

APPENDIX II.--

EQUATIONS FOR PREDICTING HEIGHTS

FROM FIELD GROWING SEASONS AND SITE.

$$(1) \text{ HEIGHT (RH60)} = -0.0716 + 1.0645(\text{fgs}) + \\ 0.3644(\text{TSC})(\text{fgs})$$

where: HEIGHT is in feet; observed values for height = (0.6 x measured value).

fgs = number of field growing seasons.

TSC = topographic site coefficient (see Appendix I).

$R^2 = 0.89$; $p = <0.01$, $n = 382$; $Sy \cdot x = 2.65$; regression coefficients are significantly different from 0 at the 0.01 level.

$$(2) \text{ HEIGHT (RH80)} = -0.0954 + 1.4194(\text{fgs}) + \\ 0.4859(\text{TSC})(\text{fgs})$$

where: HEIGHT is in feet; observed values for height = (0.8 x measured value).

fgs = number of field growing seasons.

TSC = topographic site coefficient (see Appendix I).

$R^2 = 0.89$; $p = <0.01$; $n = 382$; $Sy \cdot x = 3.53$; regression coefficients are significantly different from 0 at the 0.01 level.

Topographic site coefficients at Albany ranged from 0.27 to 0.63, and at Coulee from 0.62 to 0.85.

APPENDIX III.--REGRESSION EQUATIONS
FOR HEIGHT ATTAINMENT PROBABILITIES

ESTIMATED FROM AGE

Regression estimates in figures 2 and 3 are based on the logistic function and a model that restricts probability estimates (P) to a closed interval of 0 to 1 (Hamilton 1974). The model can be expressed as:

$$P = \{ 1 + \exp[-(B_0 + B_1X_1 + B_2X_2)] \}^{-1}$$

where X_1 = number of field growing seasons (fgs) and X_2 = fgs/(age + 1). The observed value of the dependent variable (an individual tree) assumes a value of 1 (success) or 0 (failure). For each tree the observed probability of success at time of planting (0 field growing seasons) was 1 because heights of red oak stump sprouts (the standard on which interplanting success was based) were assumed to be zero.

Because the customary measure of goodness-of-fit for regression relations, the

error mean square, is not appropriate when the dependent variable is dichotomous, goodness-of-fit was based on:

- (1) "t" tests that determine whether each of the estimated parameters is significantly different from 0,
- (2) an analysis of variance using the F statistic to test the significance of the variation explained by regression, and
- (3) a chi-square analysis that evaluates differences between observed and predicted numbers of events within probability intervals of width 0.05. (The latter test was used primarily for comparing alternative models.)

Regression equations and goodness-of-fit statistics are given in table 3.

APPENDIX IV.--DERIVATION OF PLANTING FACTORS

The following relations, based on the binomial distribution, assume interplanted trees attain "success" status independently of one another with equal probabilities.

Table 3.--Regression equations for height attainment probabilities estimated from age

ALBANY PLOTS									
Species	:	:	Regression coefficients			Significance level ¹			Observations
	Success	:	B ₁	B ₂	"t"		Chi-		
	criteria	:	B ₀	(age)	(1/(age+1))	B ₁	B ₂	squared	
:	:	:	:	:	:	:	:	:	:
(Number)									
American basswood	RH80	-4.3523	(²)	8.1425	(²)	0.01	NS	460	
	RH60	-2.5675	-0.0498	6.4988	NS	.01	NS	460	
Northern red oak	RH80	-5.3678	.2706	.1188	0.05	.01	NS	475	
	RH60	-3.5158	.1847	9.5497	.05	.01	NS	475	
Red maple	RH80	-3.3563	.3151	6.6632	.01	.01	NS	452	
	RH60	-2.0854	.2083	6.5739	.01	.01	NS	452	
Sugar maple	RH80	-3.0634	.2936	5.9674	.01	.01	0.05	470	
	RH60	-.2678	(²)	3.2682	(²)	.01	NS	470	
White ash	RH80	.4568	-.1935	5.1524	.05	.01	NS	549	
	RH60	.1981	(²)	6.6287	(²)	.01	NS	549	
Yellow-poplar	RH80	-.0159	-.1184	4.4432	NS	.01	NS	480	
	RH60	.6429	-.1565	3.8605	.05	.01	NS	480	
COULEE PLOTS									
Northern red oak	RH80 ³								
	RH60	-0.1121	0.8661	0.1563	0.01	0.01	0.01	1,004	
Sugar maple	RH80	-.1608	1.4951	.2166	.01	.01	NS	535	
	RH60	-8.1246	.8432	.1108	.01	.01	.01	535	
White ash	RH80	-8.7873	.5902	.1676	.01	.01	NS	493	
	RH60	-7.6666	.6514	.1775	.01	.01	.01	493	
Yellow-poplar	RH80	-13.2956	18.3823	1.2024	.01	.01	NS	1,008	
	RH60	-7.8944	-.7435	11.7716	.01	.01	NS	1,008	

¹NS = nonsignificant (p > 0.05); p < 0.01 for all regression F tests.

²Variable not included in equation.

³The observed probabilities were too small to permit calculation of regression.

Let:

S_n = the number of successful trees at the end of the eighth field growing season out of n trees originally interplanted;

p = the probability that a single tree will survive and reach a given relative height after eight field growing seasons (from table 1); and

q = the probability that a single tree will not survive and reach a given relative height after eight growing seasons ($q=1-p$).

The probability of having $S_n = k$ trees out of n initial trees at the end of the eighth growing season is given by the binomial distribution:

$$p(S_n = k) = \binom{n}{k} p^k \cdot q^{n-k}. \quad (1)$$

note that $p(S_n \geq 1) = 1 - p(S_n = 0)$. (2)

If we wish to produce at least one successful tree at the end of the eighth field growing season with 80 percent probability, then substituting in (2):

$$0.80 = 1 - p(S_n = 0)$$

$$p(S_n = 0) = 0.20;$$

letting $k = 0$ in (1):

$$p(S_n = 0) = \binom{n}{0} p^0 q^{n-0}$$

which reduces to:

$$p(S_n = 0) = q^n$$

$$q^n = 0.20$$

$$n \cdot \log_{10} q = \log_{10}(0.20)$$

$$n = \frac{\log_{10}(0.20)}{\log_{10} q} = \text{planting factor.}$$

Johnson, Paul S.

1976. Eight-year performance of interplanted hardwoods in southern Wisconsin oak clearcuts. USDA For. Serv. Res. Pap. NC-126, 9 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Of six species interplanted in oak clearcuttings, sugar maple, red maple, and white ash were the most successful. Other species planted were northern red oak, yellow-poplar, and American basswood. Gives numbers of trees that should be planted for each species and initial size of planting stock.

OXFORD: 237.5(775). KEY WORDS: regeneration, planting, white ash, yellow-poplar, northern red oak.

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Effect of plantation establishment on soil and soil water in SOUTHWESTERN WISCONSIN

RICHARD S. SARTZ

14 YEARS



8 YEARS

3 YEARS



CONTENTS

Previous Work.	1
The Plantings.	1
Sampling Design and Methods.	2
Results.	3
Discussion and Conclusions	6
Literature Cited	7

Richard S. Sartz retired from the Forest Service at the end of 1975, after 17 years as leader of the Station's flood and erosion research project at La Crosse, Wisconsin. He started with the Forest Service's Northeastern Forest Experiment Station at Philadelphia, Pennsylvania, in December 1947, and subsequently held research positions at Portland, Oregon, Washington, D. C., and at Laconia, New Hampshire.

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EFFECT OF PLANTATION ESTABLISHMENT ON SOIL AND SOIL WATER IN SOUTHWESTERN WISCONSIN

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In 1961 several different species of coniferous trees were planted on the Coulee Experimental Forest, in southwestern Wisconsin's "Driftless Area." One objective of the plantings was to find out how they might change the hydrologic properties of the soil, a loessal silt loam that had been in continuous agriculture for about 100 years. The area has a long history of soil erosion and flash floods, and when we began the study we thought that tree planting might be needed to control runoff and erosion on steep, eroded slopes of the area. This paper gives the results after 13 to 14 years of tree growth.

PREVIOUS WORK

How trees alter the properties of agricultural soils has been studied widely over the years. Formation of a litter layer is one obvious effect, and the role of litter in runoff prevention was the subject of much early research (Lowdermilk 1930, Kittredge 1940, Rowe 1955, Sartz 1963). In more recent appraisals, Mader and Lull (1968) and Sartz (1969) both questioned the importance of the *amount* of litter, the latter concluding that protecting the soil from raindrop impact was its most important function.

Regarding the surface soil, Billings (1938), who studied old field pine stands of different ages in North Carolina, found that organic matter increased substantially and bulk density decreased substantially between the 13th and 21st years of growth. These trends continued through the 110th year. In Ohio, Harold (1961) reported that after 20 years of pine growth the "air space porosity" in the top 8 cm of silt loam soil

had increased from 3 to 9 percent. Byrnes and Kardos (1963) reported that, other than surface organic matter accumulations and rooting habits, there were no major differences in the physical properties of three types of soil under old field and 20-year-old planted red pine in Pennsylvania.

Wilde (1964) reported little change in the organic matter content of sandy or sandy loam soils in Wisconsin pine plantations less than 20 years old; and on loessal soils in Illinois, Rolfe and Boggess (1973) found more soil organic matter and higher surface soil bulk density in old fields than in 30- to 35-year-old shortleaf pine plantations. However, the old field vegetation in their study included hardwood trees as old as 40 years.

A partial assessment of the effect of the Coulee Experimental Forest plantings on soil and water variables has already been made (Sartz and Harris 1972). After 10 years of growth we found no change in soil bulk density under larch and red pine plantations, but the litter layer was twice as heavy in the larch as in the red pine plantings or in unplanted controls. Both species were already depleting twice as much soil water as the old field vegetation on unplanted plots.

THE PLANTINGS

The trees were planted on 0.2 hectare plots at three different sites: an upper north slope of 10 percent; a lower north slope of 25 percent; and a middle south slope of 25 percent. The soil on all sites is a loessal silt loam or a mixture of loess and sand (Typic hapludalfs of the Dubuque, Fayette, and Gale-Hixton series). The lower

north slope site was former pastureland that had never been plowed, but the other two sites were fields that had been under cultivation for 100 years or more. The upper north slope ("ridgetop") site had been in corn and the south slope site in hay the year before planting.

The trees were planted in the spring of 1961 on small bench terraces made with an angle dozer (Stoeckeler 1962). Spacing was 2 by 2 m, with 500 trees per plot. The species evaluated were eastern white pine (*Pinus strobus* L.); red pine (*Pinus resinosa* Ait); white spruce (*Picea glauca* Voss); and European larch (*Larix decidua* Mill.). The red pine planting stock was 2-1, the larch 2-0, and the white pine and spruce 2-2.

The soil and water variables were also measured on one unplanted control plot at each site. These developed into "old fields" during the course of the study. The volunteer vegetation was primarily Kentucky bluegrass (*Poa pratensis*); goldenrod (*Solidago* spp.); wild carrot (*Daucus carota*); and timothy (*Phleum pratense*). The lower north slope plot had no timothy, and after a few years, blackberries (*Rubus* spp.) invaded this plot. Plants and litter completely covered the soil on all these plots.

SAMPLING DESIGN AND METHODS

Design

The soil variables were: litter accumulation; bulk density at two depths (0 to 8 and 8 to 15 cm); nitrogen and organic carbon content at two depths (0 to 4 and 4 to 8 cm); and seasonal soil water depletion in a 1-meter soil mantle. Water content of the snowpack was also evaluated.

To find out how the variables might change with tree growth they were measured at predetermined intervals over the years, starting when the plots were still essentially in an open field condition. Litter, soil bulk density, and soil nitrogen and organic carbon were measured three times (5-year intervals); water depletion, four times (2- to 5-year intervals); and snow accumulation, five times (2- to 4-year intervals). The sampling interval for water depletion and snow accumulation varied because of seasonal weather constraints.

Periodic sampling of the litter and soil required a design that would preclude sampling the same spot more than once. Accordingly, a block of 10 trees by 10 trees in the center of each planting was used as a sampling grid, with each inter-tree space (termed a "sampling block") being assigned a number from 1 to 100. The sampling blocks to be used for each set of samples for each variable were assigned at the beginning of the study, and were mechanically spaced within the 100-sampling block grid. Litter sampling required 10 blocks per set, soil sampling, 5 blocks per set. The unplanted control plots were sampled in the same way, except that the sampling grid was marked with numbered stakes.

Soil bulk density was sampled in the late summer or fall, and litter and soil nitrogen and organic carbon in early spring of the following year; thus, all were sampled at the same stage of tree growth.

Sampling on the planted plots was complicated by the planting furrows, which produced three different soil conditions: the furrow; the overturned furrow slice; and the undisturbed area. I decided to sample litter and bulk density in both the furrow and the undisturbed area. The furrow was sampled at one point (midway between trees in the same row) and the undisturbed area at two (midway between trees in adjacent rows and midway on the diagonal between trees in adjacent rows and columns). Nitrogen and organic carbon were sampled only on the undisturbed area and only on the pine and open plots at the middle and lower slope sites.

Soil water depletion was determined from neutron measurements near the center of the sampling grid. Control plots were sampled at two points 6 m apart, planted plots at two pairs of points 6 m apart. The pairs consisted of one point .6 m from a tree and one 1.4 m from a tree. The purpose of the pairs was to see if the amount of water depletion differed at the two distances, and if so, how long the difference might persist as the trees grew.

Snow accumulation was measured on a single transect near the center of each plot. Depth was measured at 10 points, 1 m apart, and water content at 5 points, 2 m apart.

Methods

Surface organic matter was sampled with a 30- by 30-cm frame lowered to the ground from a vertical position above the plot. The litter, F-layer and dead standing herbaceous vegetation inside the frame were included in the sample. The samples were collected in paper bags and air dried before weighing.

Soil bulk density was determined from 300 cc (7.3 by 7.1 cm) undisturbed cores, and soil nitrogen and organic carbon from 21 mm diameter tube sampler cores. The latter were taken at litter sampling points. Two cores were taken at each point, and the cores from all points on a plot were composited. Thus, one composited sample consisted of 20 cores (2 times 10 sampling points). Nitrogen content was determined by the Kjeldahl method, and organic carbon content by the dichromate oxidation method (Mebius 1960).

Soil water depletion was determined from water content measurements made with the neutron meter at three depths: 30-, 60-, and 90-cm. Seasonal depletion was assumed to be the difference between early spring and late summer water contents.

Snow depth and water content were measured with the Mt. Rose snow tube and tubular scales. The measurements were made at the estimated time of maximum snow accumulation--usually late February or March--in the years when a continuous snowpack built up.

RESULTS

Litter

The first litter sample, taken the third year after planting, consisted mostly of dead grass and weeds, except for varying amounts of old cornstalks in the ridgetop samples. Individual sample weights varied greatly, depending upon the presence or absence of individual heavy stalks--such as mullein. Regardless of weight, the litter completely covered the ground at most sampling points outside the furrows. However, it was still sparse in the furrows (fig. 1).

Five years later (8 after planting) the furrows of the pine and larch plots showed an increase in litter, but the area outside the furrows in the red pine and

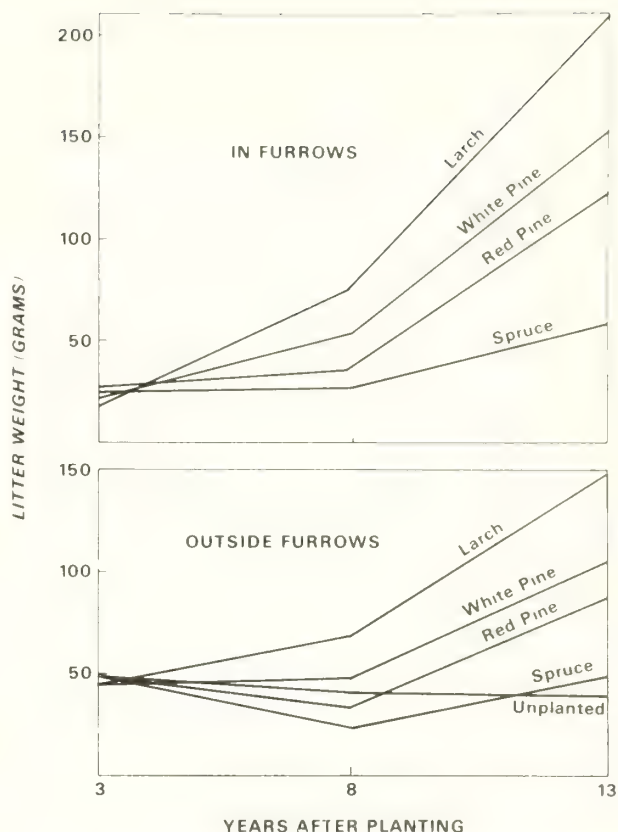


Figure 1.--Mean litter weight in and outside planting furrows.

spruce plots showed a decrease from the previous sample (fig. 1). The latter reflects a decrease in herbaceous growth with increased shading of the plots.

Eight years after planting mosses had started to come in on the more shaded spots, especially in the furrows, and live moss was included in the litter sample where it could be separated from the mineral soil. Cornstalks, common on ridgetop plots in the first sample, were not found in the second. Bluegrass was the predominant cover on most plots, with wild carrot and golden rod stems making up a large part of the weight in some samples. However, litter on the larch plots was mostly from needle fall, which produced a net increase in litter in both the furrow and unfurrowed samples (fig. 1). The pine canopies had started to close and the larch canopy was almost completely closed, except where trees had died. Mean tree heights ranged from 1.3 m for spruce to 5.9 m for larch (table 1).

Table 1.--Tree heights¹ on three sites at time of litter and soil sampling
(Meters)

Species	Ridge			North			South		
	1964	1969	1974	1964	1969	1974	1964	1969	1974
White pine	1.1	2.4	6.8	1.6	3.9	8.7	1.4	3.7	7.5
Red pine	.9	2.5	6.1	1.1	3.1	6.9	1.0	3.0	6.8
Spruce	.6	1.3	2.4	.8	2.4	5.6	--	--	--
Larch	1.6	5.5	² 11.0	2.0	5.9	² 12.0	--	--	--

¹From 10 trees on each plot.

²Estimated from general height of the plantation, rather than individual trees.

By the 13th year, the litter on all planted plots was heavier than on the unplanted controls except for the ridgetop spruce plot in which the canopy was not yet closed. The larch litter formed a continuous mat--in places as much as 4 cm thick. White pine litter was also thick. However, the white pine was pruned twice (in the fifth and ninth years after planting) for blister rust control, and the needles from the pruned branches became part of the litter. So the white pine litter was probably heavier than it would have been without pruning. The litter on both the larch and white pine plots had been partially intermixed with the soil by earthworms.

Neither the red pine nor the spruce needles formed a continuous soil cover, but cones were common. Dead needles that were unavoidably dislodged from the lowest five whorls of the red pine during sampling may have increased variation in the red pine samples. Moss was still common on the ridgetop spruce plot, but grew only in scattered patches of sunlight under the more closed canopy of the north slope spruce plot.

Differences in litter accumulation at 1.0 and 1.4 m from the trees were evident in the 8th year sample, and obvious in the 13th year sample (fig 2).

The litter sampling method was designed to give point values for comparison among cover types rather than unbiased estimates of mean litter weight on the plots. However, the sample taken midway between trees in adjacent rows may give a reasonable estimate of mean litter weight on the plots. Assuming this, I computed weight per acre to allow comparison with results from other studies. The mean values 13 years after planting for all plots sampled were, in metric tons per acre: larch, 6.36; white pine, 4.53; red pine, 3.75; spruce, 2.13; and unplanted,

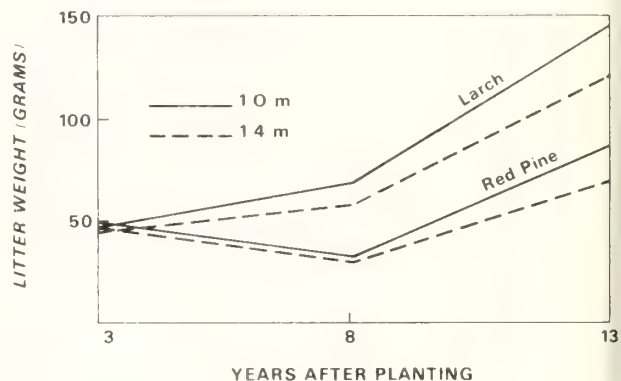


Figure 2.--Mean larch and red pine litter weight at 1.0 and 1.4 m from trees.

1.61. For 18-year-old stands in New York, Day (1940) reported values of 5.49 for white pine, and 5.73 for red pine.

Soil Bulk Density

In general bulk density of the top 8 cm of soil seems to have decreased, both on planted and unplanted plots. However, great variation in the samples (coefficients of variation were as high as 17 percent) made the results inconclusive. Since the values for the two undisturbed positions on planted plots agreed closely, I combined them for an analysis of differences (table 2). There appeared to be more change in the first 5-year period than in the second, more in furrows than on undisturbed areas, and more on ridgetop plots than on the others. A difference by sites is not surprising, since bulk density was different initially on the three sites (table 3).

Perhaps the most convincing evidence of a real bulk density change in the 0-8 cm sample was the apparent lack of change in the 8-15 cm sample (table 3).

Table 2.--Change in bulk density in the top 8 centimeters of soil on three sites (Grams per cubic centimeter)

Site and species	Undisturbed ¹		Furrows ²	
	1963-1968	1968-1973	1963-1968	1968-1973
Ridge:				
White pine	-.10*	+.05	-.05	-.01
Red pine	-.10*	-.01	-.09*	.00
Spruce	-.05	-.08*	+.03	-.13*
Larch	-.06*	+.01	-.10	.00
Mean	-.08	-.01	-.05	-.04
Unplanted	-.07	.00	--	--
North:				
White pine	+.01	+.03	-.11*	-.01
Red pine	+.04	.00	-.03	-.09*
Spruce	+.05	-.10*	-.01	-.07
Larch	-.10	+.09*	-.04	-.07
Mean	.00	.00	-.05	-.06
Unplanted	.00	-.11*	--	--
South:				
White pine	-.01	+.02	-.10	+.02
Red pine	-.04	-.02	-.06	-.02
Mean	-.02	.00	-.08	.00
Unplanted	+.08*	-.10*	--	--

¹n = 10

²n = 5

* Significant at 5 percent level as tested by "T".

Table 3.--Mean bulk density of planted plots at two depths and three sites¹ (Grams per cubic centimeter)

0 to 8-cm Depth					
Site	Sampling position	Years after planting:			10-year difference
		3	8	13	
Ridge	Undisturbed	1.15	1.08	1.07	-.08
	Furrow	1.24	1.19	1.15	-.09
North	Undisturbed	1.01	1.00	1.01	.00
	Furrow	1.26	1.21	1.15	-.11
South	Undisturbed	1.30	1.28	1.28	-.02
	Furrow	1.40	1.32	1.32	-.08
8 to 15-cm Depth					
Ridge	Undisturbed	1.22	1.24	1.26	+.04
	Furrow	1.34	1.34	1.35	+.01
North	Undisturbed	1.18	1.18	1.15	-.03
	Furrow	1.36	1.33	1.37	+.01
South	Undisturbed	1.38	1.38	1.38	.00
	Furrow	1.42	1.39	1.43	+.01

¹The ridge and north sites had 40 undisturbed and 20 furrow samples; the south site 20 undisturbed and 10 furrow samples.

Soil Nitrogen and Carbon

Because the data for separate sampling positions and depths showed no readily apparent trends, I combined them for further study. The measured values for both elements decreased on all north slope plots and on the south slope white pine plot, but increased on the south slope red pine and unplanted plots (table 4). Whether the differences reflect real soil changes or sampling error is debatable. The nature of the data precluded statistical testing.

Table 4.--Mean nitrogen and carbon content of surface 8 centimeters of soil on two sites (Percent)

Site and species	Nitrogen			Carbon		
	Years after planting:			Years after planting:		
	3	8	13	3	8	13
North:						
White pine	0.260	0.204	0.202	5.8	4.9	4.4
Red pine	.218	.186	.195	5.0	4.8	4.1
Unplanted	.268	.239	.202	5.8	5.3	5.4
South:						
White pine	.064	.062	.053	1.4	1.8	1.2
Red pine	.092	.118	.124	1.9	2.6	2.7
Unplanted	.124	.236	.223	2.6	6.1	5.2

Soil Water Depletion

Three years after planting, when the first soil water measurements were taken, planted plots were still depleting about the same amount of water as the unplanted controls. By the 8th year, however, most planted plots were depleting much more than the controls; and by the 14th year, there were 2- to 3-fold differences (table 5). The ridgetop spruce plot did not conform to the general pattern, probably because of shallower soil. Although it is adjacent to the control, it is downhill from it on a steeper grade where erosion losses over the years of cultivation would have been greater. The canopy was still open on this plot, and the trees were less than half as tall as the spruce on the north site (table 1).

Measurements taken in the 10th year on the red pine and larch plots and in a natural oak-hickory saw-timber stand (Sartz 1972b) provide a 2-year interval comparison of depletion by the plantations with depletion by a natural hardwood stand growing on similar north slope sites. Depletion was about the same in the 8th year of plantation growth, but plantation depletion was greater in the 10th and 14th years (table 6).

The small 12th-year depletion differences are misleading (table 5). In years of high growing season rainfall (280 mm fell in July-August of the 12th year compared with 105-155 mm the other years) seasonal depletion, which is the difference between the amounts stored in the soil in the spring and fall, does not give a good index of comparative water use.

Snowpack

The amount of snow accumulation, as measured midway between rows of trees at

time of maximum accumulation, was not clearly affected by tree species up to the 10th year after planting (table 7). Mean snowpack water content on planted plots was greater than on open plots on the ridge and south sites, but about equal on the north site. However, the trees affected the pattern of melt within the plantations. This was very evident during snowmelt in 1975. There were still snow accumulations as deep as 50 cm between trees from crown dumping or shading when bare ground was already showing around the trees. These accumulations were deeper on the two north slope plots than on the south slope plot, and were deepest on spruce plots. Among planted plots, the snow surface was most even in the larch.

Table 5.--*Water depletion in a 1-meter soil mantle on planted and unplanted plots at three sites*
(Centimeters)

Site and species	Years after planting			
	3	8	12	14
Ridge:				
White pine	7.6	5.9	3.5	11.1
Red pine	8.0	8.9	3.0	12.0
Spruce	9.2	6.1	1.2	5.4
Larch	9.0	9.3	8.1	15.0
Unplanted	7.0	5.1	1.3	6.3
North:				
White pine	6.8	7.9	3.0	11.8
Red pine	8.1	8.1	1.7	12.1
Spruce	10.6	7.1	1.3	9.2
Larch	5.3	9.0	1.6	10.2
Unplanted	10.7	3.7	.6	3.5
South:				
White pine	12.6	8.7	7.6	11.2
Red pine	11.1	8.7	8.0	11.8
Unplanted	11.3	4.8	1.5	4.5
Mean:				
White pine	9.0	7.5	4.7	11.4
Red pine	9.0	8.5	4.3	12.0
Spruce	9.1	6.6	1.3	7.3
Larch	7.2	9.2	4.9	12.6
Unplanted	9.6	4.5	1.1	4.7

Table 6.--*Water depletion in a 1-meter soil mantle by planted red pine and larch compared to depletion by natural hardwoods*
(Centimeters)

Vegetation	Years after planting			
	8	10	12	14
Red pine	8.1	12.8	1.7	12.1
Larch	9.0	11.8	1.6	10.2
Hardwoods	8.6	10.5	2.7	7.8

Table 7.--*Snowpack water content by species and sites 10 years after planting*
(Millimeters)

Species	Ridge	North	South
White pine	155	147	109
Red pine	170	163	137
Spruce	193	152	--
Larch	175	160	--
Mean	173	156	123
Unplanted	142	157	91

The amount of snow accumulation was also affected by site, as previously reported (Sartz 1972a).

DISCUSSION AND CONCLUSIONS

This study was planned to tell us how different tree species might change the soil as they grow from small planted seedlings to dense plantations. When we began the study we thought that tree planting might be an effective flood prevention practice on steep, eroded slopes of the area. Since then, however, we have found that maintaining a soil cover is the real key to runoff control; and that simply retiring land from active agriculture reduces its runoff potential drastically (Sartz 1970, 1975, Sartz and Tolsted 1974). Because of this, some of the things learned from this study may now be "after the fact," so-to-speak. Nevertheless, the information adds to the general pool of knowledge on forest-soil relationships.

The much greater amounts of litter that built up under larch would seem to make it a preferred species for watershed management planting; however, the additional litter may have no value in preventing rainfall runoff (Mader and Lull 1968). It may have value in reducing soil freezing, which could reduce snowmelt runoff. However, this has yet to be demonstrated experimentally. The temporary litter decrease during the transition from grasses and weeds to tree needles (fig. 1) is interesting, but probably of little importance to the runoff process.

The plantations are not yet old enough to have reduced soil bulk density much; but this also may not be important, since the soil is already absorbing most of the rainfall anyway.

By the 10th year, the pine and larch plantings were using substantially more water from the top meter of soil than the unplanted controls, and a little more than a natural hardwood forest. The additional water depleted by the trees can reduce flood runoff potential from summer storms because it enlarges the soil water storage reservoir. On the other hand, this may reduce the contribution to ground water, springflow, or stream base flow, which would have a negative effect on water production.

Depletion values reflect rainfall gains as well as evapotranspiration losses. So the values would vary from year to year, even with an unchanging vegetation. Thus, in the 12th year (1973) the high growing season rainfall tended to mask the losses from evapotranspiration. Differences in the length of the depletion period would also affect the amount of depletion measured from one year to another. These are inherent weaknesses in the depletion method of assessing comparative water use by different vegetations.

The snow sampling method used was not adequate for determining mean snow accumulation in young forest plantations. The uneven distribution of snow caused by interception, crown-dumping, and irregular shading, requires a much more intensive sample for an unbiased estimate of the true snow cover. And even with an adequate sampling design, getting good measurements in unpruned stands would be difficult because of access problems.

When this study was conceived I had planned to follow changes in the variables with tree growth for longer than 14 years. However, after finding that tree planting is not really needed to prevent runoff and erosion in the Driftless Area, I decided to terminate the study with this report. The second objective of the plantings--to determine the adaptability of several species to different sites of eroded loess soil--has been partially met; but further observations on growth should be made at appropriate intervals to assess the wood products potential over a longer period of time.

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Changes in litter weight, soil bulk density, soil nitrogen and organic carbon contents, soil water depletion, and snowpack accumulation were evaluated over 14 years of plantation growth on three different sites. The species studied were white and red pines, white spruce, and European larch, along with unplanted controls.

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ESTIMATING WATER YIELD DIFFERENCES BETWEEN HARDWOOD & PINE FORESTS

AN APPLICATION OF NET PRECIPITATION DATA — BY ELON S. VERRY



THE AUTHOR

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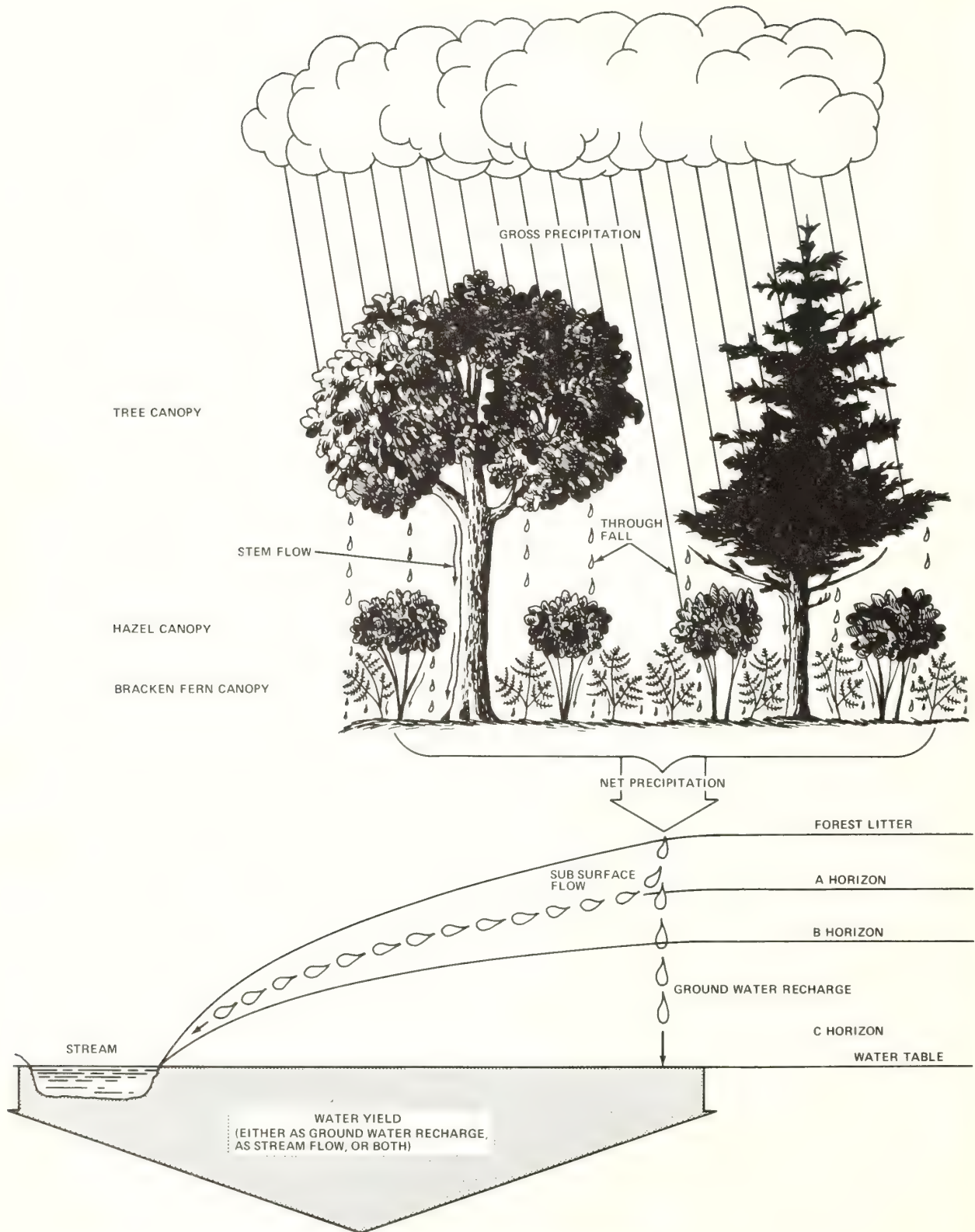
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CONTENTS

Introduction	1
Historical Perspective	2
Applications	3
Literature Cited	5
Appendix I--Glossary of Terms	6
Appendix II--Derivation of Application Procedures. .	7
Appendix III--Documentation for Aspen and Red Pine Equations	7
Appendix IV--Documentation for Black Spruce Equations	12

PICTORIAL DEFINITION OF TERMS



ESTIMATING WATER YIELD DIFFERENCES BETWEEN HARDWOOD AND PINE FORESTS: AN APPLICATION OF NET PRECIPITATION DATA

Elon S. Verry

INTRODUCTION

The impact of different forest types on streamflow or groundwater recharge must be considered in evaluating multiple-use alternatives. The impact of species conversion on streamflow has been directly measured at the Coweeta Experimental Watersheds in North Carolina. However, the use of net precipitation¹ data, with appropriate cautions, provides a practical basis for estimating water yield differences between forest types where long-term streamflow comparisons are not available.

The use of net precipitation differences among hardwood and pine forests as an estimate of water yield differences should not be interpreted as a total explanation of processes affecting water yield. It is only an arbitrary, conservative estimate of species effects on water yield. It does provide a practical working tool with objective values.

This paper presents net precipitation data for stocking levels of one aspen and three red pine forests in north-central Minnesota described in table 1. Net precipitation data for aspen are similar to data for all eastern hardwood forests (Helvey and Patric 1965), and data for red pine are similar to net precipitation data for all eastern pine forests (Helvey 1971). Thus relationships derived in this paper are applicable to other hardwood and pine forests in the northern Lake States.

¹ See drawing on page ii and the Glossary of terms for definitions.

Table 1.--*Characteristics of forests to which net precipitation relations were applied*

Forest components:	Basal area: <i>m²/ha</i>	Stems <i>No./ha</i>	Crown height: <i>m</i>	Crown coverage: <i>Percent</i>	Age: <i>Years</i>	Site index <i>age 50</i>
Aspen	23.0	1,112	23.2	82	52	22.9
Hazel	--	42,000	2.6	80	--	--
Bracken	--	32,865	--	52	--	--
Red pine	13.8	215	19.8	--	67	16.8
Hazel	--	33,357	2.1	80	--	--
Bracken	--	30,641	--	48	--	--
Red pine	23.0	470	20.4	--	67	16.8
Hazel	--	15,815	2.0	50	--	--
Bracken	--	26,193	--	41	--	--
Red pine	32.1	675	20.7	--	67	16.8
Hazel	--	15,073	1.1	46	--	--
Bracken	--	19,027	--	30	--	--

¹ Basal areas of 13.8, 23.0, and 32.1 m²/ha correspond to basal areas of 60, 100, and 140 ft²/acre. See Appendix I, page 6 for other conversion factors.

The assumptions in this paper are many and result from the combination of many separate studies to bear on a single application. As with any modeling approach, the necessary assumptions point up our lack of knowledge or areas of disagreement. Rainfall components are derived from relatively straight forward application of specific studies. However, we assumed seasonal net snowfall to be the maximum snowpack water content. This, of course, is incorrect because it does not account for overwinter melt that may infiltrate the soil or for additions to the snowpack from soil water.

The literature contains many conceptual analyses of snowfall interception (Miller 1964, 1967, Anderson 1970) from which the authors conclude that simple snow tube

measurements cannot explain the interception process. In addition, at least two studies have shown that overwinter snowmelt increases soil water and streamflow (Federer 1965, Haupt 1972).

Our data from the Marcell Experimental Forest (Ca. N 47° 32' Lat., 93° 28' W Long.) showed that any overwinter melt from the bottom of the snowpack that does occur is not sufficient to produce shallow subsurface flow let alone streamflow: (1) runoff plots that measure both surface and shallow subsurface flow have never yielded flow over the winter period; and (2) shallow water tables recede slightly over winter even in sealed, perched basins from where there is no streamflow. Furthermore, we have never observed crown drip during this period in north-central Minnesota; a process that Haupt (1972) showed to be a significant source of winter soil water recharge in Idaho.

These observations do not tell us whether or not snowpack water entered the soil to satisfy soil water storage deficits, but they do indicate that it is not sufficient to affect streamflow, or even local subsurface flow. In the severe continental climate of north-central Minnesota, at least, it does appear to give a useful estimate of maximum snowpack water content and the effect of forest types on it.

HISTORICAL PERSPECTIVE

In 1965, Dr. J. Delfs (1967) of Lower Saxony, Germany, proposed a practical assessment of interception data. He stated:

"Preliminary results suggest that it is chiefly interception which is responsible for the effect of beech and spruce stands on the water regime. ...The beech area discharged over 200 millimeters (mm) more than the spruce area."

This was a bold statement indeed. The concept was met with arguments that interception differences might be balanced by differences in tree transpiration.

Dr. Delfs' proposal gained considerable credence in 1968 when Swank and Miner reported the effect on streamflow of converting a hardwood watershed to white pine. When the white pine trees were only 10 years old, streamflow had decreased by 94 mm. In their first report, they stated:

"Although results reflect a specific set of . . . conditions, and identical water yield reductions would not be expected elsewhere, the evaporation processes involved are universal. Thus a trend toward reduction in total water yield should also be expected in other regions." (Swank and Miner 1968).

Four years later streamflow had been reduced by 178 mm. Thus, in a second report, they concluded, "...that increased interception loss occurs when hardwood-covered watersheds are converted to white pine, causing significant reductions in streamflow . . ." (Swank, Goebel, and Helvey 1972). These conclusions are further supported in a 15-year summary published by Swank and Douglas in 1974.

An important and practical finding of Swank and Miner's study is that the differences in net precipitation are a conservative estimate of differences expected in streamflow. Streamflow differences may in fact be greater because transpiration by pines during leafless periods is probably greater than that of hardwoods (Swank, Goebel, and Helvey 1972). These concepts should even apply to other areas in humid regions.

Swank, Goebel, and Helvey (1972) applied this concept to assess the impact of large scale conifer plantations on streamflow throughout the southeastern United States. They used interception studies for hardwoods developed throughout the eastern United States and interception studies for loblolly pine developed at Clemson, South Carolina. Their estimate of streamflow differences at Clemson is 102 mm (4 inches). However, the absolute amount of interception loss or net precipitation for any given forest is primarily determined by the amount of annual precipitation. Thus differences between hardwood and pine forest net precipitation will be less in dry areas than in wet areas.

In areas where multiple-use decisions dictate pine, lower stocking levels could be maintained to enhance water yield or vice versa. Thinning in pine stands has increased water yield (Urie 1971, Van Der Zell 1970); however, long-term streamflow data are not available to assess how long the effect will last.

Thinnings in hardwood stands have caused small increases in streamflow that,

are probably real although they were not statistically significant (Reinhart, Eschner, and Trimble 1963, Douglass and Swank 1972).

APPLICATIONS

The aspen and red pine data are applicable to most areas, but there are conditions where differences in net precipitation may not be realized as differences in water yield. These occur where infiltrated water is evapotranspired before it passes below or away from plant roots; either because (a) plant roots reach to the water table or (b) additional water does not contribute to deep percolation or shallow subsurface flow because it is insufficient to satisfy soil water deficits around macropores.

To determine differences in water yield for a given area of land with total conversion:

- A. First obtain your average annual precipitation for the area in question.
- B. Enter figure one along the annual gross precipitation scale and proceed upward to intersect the 23 m²/ha red pine line.
- C. From the point of intersection on the red pine line proceed to the left scale and read the intersected value of net precipitation.
- D. Repeat the procedure using the aspen line.
- E. The difference in net precipitation will increase water yields for red pine-to-aspen conversions and decrease water yields for aspen-to-red pine conversions.

For example, average annual precipitation is 756 mm for the Marcell Experimental Forest in north-central Minnesota. By entering the base of figure 1, we can estimate that net precipitation is 633 mm for the 23 m²/ha aspen stand 567 mm for the 23 m²/ha red pine stand: a difference of 66 mm. Therefore, this would mean that water yield would be increased or decreased 35 percent because the average streamflow on the Marcell Experimental Forest is 189 mm.

This same principle can be used for planning purposes on large administrative units (District, Forest, or other large area). For example, a district ranger can use his management plan to list the hectares of conversions scheduled for

the future (5, 10 yrs., etc.). He must then take the difference between the proposed total area of hardwood-to-pine conversions and pine-to-hardwood conversions. This difference must be translated to a percentage of the total planning unit area. Then he can:

- A. Enter figure 2 along the net percent change scale and proceed upward to intersect the precipitation-runoff regime line nearest to your situation.
- B. From the point of intersection on the precipitation-runoff line proceed to the left scale and read the percent change in existing water yield for the entire planning unit.
- C. Multiply the decimal percent change in water yield by the existing water yield to calculate the proposed change in water yield.
- D. If the total volume of water yield change is desired, multiply the change in water yield by the total area of the planning unit.

If on a planning unit area of 100,000 ha, for example, 2,000 ha are planned for pine-to-hardwood conversion, and 13,000 ha are planned for hardwood-to-pine conversion, then the net percent change

$$\left(\frac{13,000 - 2,000}{100,000} (100) \right)$$

would be 11 percent. If we assume that the average annual precipitation is 700 mm and the average annual runoff is 190 mm for the planning area, we would enter figure 2 at 11 percent (horizontal axis) on line B and find that the percent change in water yield on the entire planning unit is 3.7 (see dotted line). This means that the decrease in annual water yield

$$\left(\frac{(3.7)(190)}{(100)} \right)$$

is approximately 7 mm because the net conversion is from hardwood to pine forests.

The total decrease in water yield volume would be:

$$\begin{aligned} (0.007 \text{ m})(100,000 \text{ Ha}) &= 700 \text{ ha-m} \\ (700 \text{ ha-m})(8.107) &= 5,675 \text{ acre-feet} \\ (5,675 \text{ acre-feet})(325,851) &= 1.8 \times 10^9 \text{ gallons} \end{aligned}$$

This would approximate the annual needs of a community of 50,000 assuming total storage (based on a per capita consumption of 100 gallons per day).

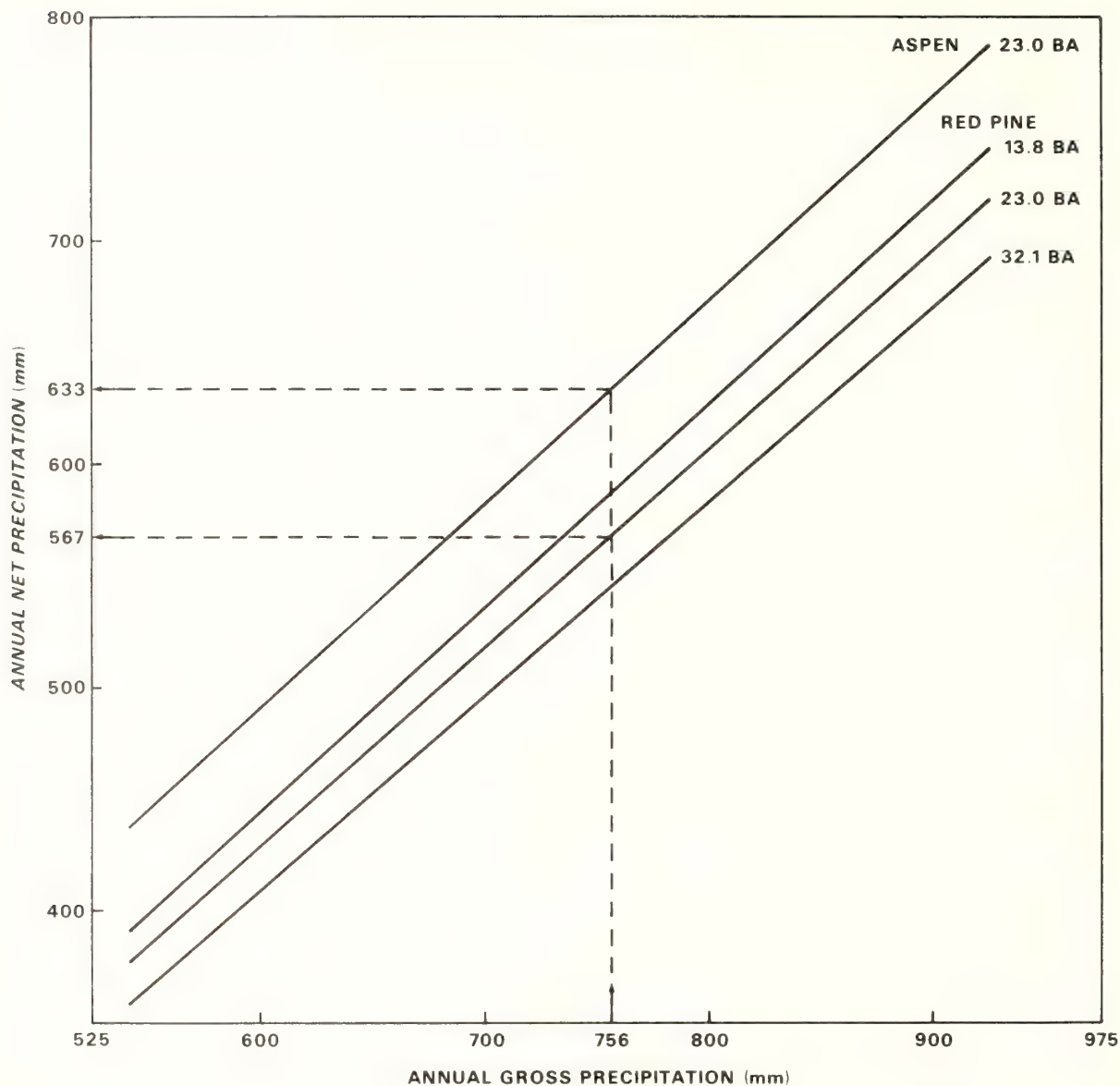


Figure 1.--The relation between net and gross annual precipitation for aspen and red pine forest (23 and 13.8, 23, 32.1 m²/ha basal area respectively).

The four precipitation-runoff lines in figure 2 were taken from precipitation and runoff graphs for the northern Lake States. Lines for a specific area in the northern Lake States can be easily developed using local data as follows:

- A. Determine the difference in net precipitation (ΔNP)² between aspen and red pine forests following the five steps

² See Appendix II, page 7, for further definitions of the symbols.

shown for determining differences on a given area of land with total conversion (see page 3).

- B. Obtain your average annual runoff (Q).
- C. Assuming a 100 percent conversion, calculate the percent change in existing water yield on the entire planning unit area as follows:

$$\frac{\Delta NP}{Q}(100) = \% \text{ change } (\Delta Q)$$

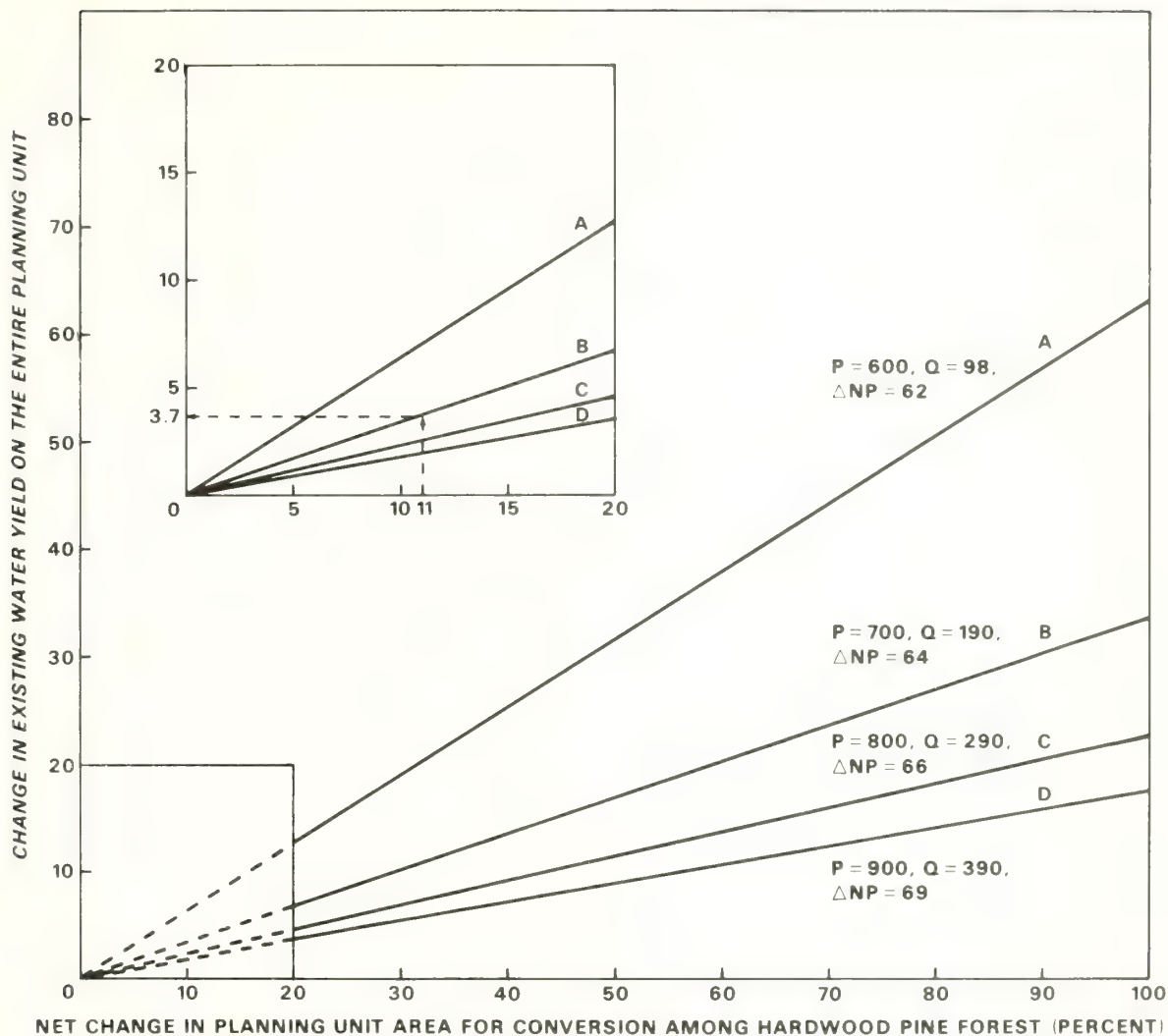


Figure 2.--The relation between net percent change in planning unit area and percent change in existing water yield for hardwood-pine conversions at four levels of precipitation (P), water yield (Q), and differences in net precipitation (ΔNP).

- D. Draw your figure 2 line by plotting the point $X' = 100$; $Y = \Delta Q$ and drawing a line from there through the origin.

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APPENDIX I--GLOSSARY OF TERMS

Gross precipitation (P): The amount of rain or snow falling above the forest as measured in small forest openings.

Interception loss: The amount of water retained on plants and subsequently evaporated.

Net precipitation (Net P): The amount of water falling on (rain) or accumulating on (snow) the litter. The end of snow accumulation is defined as the time when water content in the snowpak is maximum.

Stemflow (S): The amount of rain that reaches the ground by flowing down plant stems.

Throughfall (T): The amount of rain passing through a plane just below the identified canopy exclusive of stemflow. It is adjusted to reflect the density of the canopy in question. Adjustments are made

on a basal area basis for trees and a percent crown coverage basis for hazel and bracken fern.

Water Yield: The amount of water measured as streamflow or groundwater recharge. All precipitation components are expressed on an equivalent area-depth basis, in millimeters (mm).

Conversion Factors

(inches)(25.4) = mm
 (feet)(0.3048) = m
 (acres)(0.4047) = ha
 (ft²/acre)(0.22957) = m²/ha
 (millimeters)(0.03937) = in.
 (meters)(3.2808) = ft.
 (hectares)(2.47104) = acres
 (m²/ha)(4.35603) = ft²/acre

APPENDIX II--DERIVATION OF APPLICATION PROCEDURES

The following equation will illustrate the derivation of application procedures for evaluating large planning units:

$$\Delta Q = \frac{Q_n - Q}{Q} (100)$$

or

$$\Delta Q = \frac{\left(\frac{\Delta A}{T} \times 100\right)(q_n) + \left(100 - \frac{\Delta A}{T} \times 100\right)(Q)}{Q} - [100]$$

where:

T = total planning unit area

H_e = existing hardwood area

H_d = desired hardwood area

$\Delta A = |H_e - H_d|$ = absolute value of net area changed from hardwood to pine or vice versa

Q = existing water yield (area basis)

ΔQ = percent change in existing water yield
 ΔNP = difference in net precipitation for hardwood and pine forests on the planning unit

q_n = Q - ΔNP = water yield from converted area (subtract ΔNP for hardwood to pine conversions; add for the converse).

U = T - ΔA = net area on planning unit which is unchanged

Q_n = the new estimate of water yield on the entire planning unit.

$$Q_n = \frac{(\Delta A)(q_n) + (U)(Q)}{T}$$

Other data can be utilized in the foregoing procedure by simply substituting for the ΔNP term. For instance, differences in soil water depletion, streamflow response to clearcutting, and actual streamflow following conversions could be utilized if available.

APPENDIX III--DOCUMENTATION FOR ASPEN AND RED PINE EQUATIONS

Two basic equation forms were used; one for net storm rainfall and one for net seasonal snowfall. The general equation for individual rain storms was:

$$\text{Net P} = AT_B + BT_H + CT_T + S_B + S_H + S_T \quad (1)$$

where: Net P = Net storm precipitation (rainfall) reaching the ground

T_B = Throughfall under bracken fern

T_H = Throughfall under hazel

T_T = Throughfall under trees

A, B, C = Coefficients reflecting the percent coverage of holes in successively lower canopies

S_B = Stemflow down bracken fern stems

S_H = Stemflow down hazel stems

S_T = Stemflow down tree stems

All components are expressed on a mm basis. The basic form was modified for dormant season rainfall by deleting the bracken fern components. The dormant season was defined annually as including two periods: October 1 until the first snow and the last snow until May 15.

The tree throughfall and stemflow values were derived using the equations in

tables 2, 3, and 4. The hazel T and S values are derived from equations using tree throughfall as the independent variable; and the bracken fern T and S values are derived from equations using hazel throughfall as the independent variable. Exceptions to this progression are sometimes used to take advantage of various independent studies. Where available each equation has the variance ($S^2_{y \cdot x}$) and number of data sets going into it (N) listed.

Annual net snowfall was calculated using only one equation for the entire snow year. The general equation is:

$$MP = A + BP \quad (2)$$

where:

MP = The maximum water content occurring in the snowpack for a given year,

P = Standard snow gage precipitation (shielded, ethylene glycol and oil charged standard U.S. Weather Bureau snow gages) for the period between the first snowfall to stay on the ground and the time of maximum snowpack water content.

A, B = Coefficients in a first degree polynomial.

Table 2.--*Stemflow, throughfall, and net precipitation equations for a 23 BA aspen, hazel, bracken fern forest, growing season conditions*
(In mm)

Component	:	Equation ¹	: S ² _{y·x} : N ³ : Source
Aspen stemflow		(S _A) = -0.051 + 0.040 P	0.0017 27 (4)
Aspen-hazel throughfall		(T _{A-H}) = -1.041 + 0.858 P	.0152 28 (4)
Hazel stemflow		(S _H) = (4.2)(0.001T _A ^{1.451})(2.6)(2.06 T _A ^{-0.182})	- 36 Clements 1971
Bracken fern stemflow		(S _B) = (3.2865)(0.034)(T _{A-H})(0.873)	.021 ² 8 Clements 1971
Bracken fern throughfall		(T _B) = -0.250 + 0.76 T _{A-H}	.109 8 1971
Net precipitation (Net P)		(Net P) = 0.52 T _B + 0.48 T _{A-H} + S _A + S _H + S _B	- - -

¹ P=gross rainfall; T_A = T_{A-H} + 0.058 P + 0.23 calculated from Clements 1971; 4.2 and 3.2865 = No. stems per ha ÷ 10,000; 2.6 = mean height of codominant hazel stems (in m); 0.52 = decimal percent of bracken fern crown coverage, 0.48 = decimal percent of "holes" in bracken fern canopy.

² S²_{y·x} refers to single stem equation (delete area factor of 3.2865).

³ N = number of data sets in each equation

⁴ Verry, unpublished data. (A 1969 and 1970 interception study at the Marcell Experimental Forest in the aspen stand described in table 1. Stemflow was measured by area on two 0.016 ha plots with 12 trees each. Throughfall measured in 25 randomly located rain gages setting on the ground beneath the tree and hazel canopies.)

Table 3.--*Stemflow, throughfall, and net precipitation equations for a 23 BA aspen, hazel forest, dormant season conditions*
(In mm)

Component	:	Equation	: S ² _{y·x} : N : Source
Aspen stemflow ¹		(S _A) = -0.051 + (0.040)(1.5) P	- - Verry, Helvey & Patric 1965 ¹
Aspen throughfall		(T _A) = -0.381 + 0.914 P	- - Helvey & Patric 1965
Hazel stemflow		(S _H) = (4.2)(0.001T _A ^{1.451})(2.6)(2.06 T _A ^{-0.182})	- 8 Clements ²
Hazel throughfall ³		(T _H) = -0.13 + 0.95 T _A	- - Helvey & Patric 1965
Net precipitation ⁴		(Net P) = 0.20 T _A + 0.80 T _H + S _A + S _H	- - -

¹ Slope term multiplied by 1.5

² Based on a few measurements there is no difference between dormant and growing season stemflow relations (Personal Communication with Dr. John R. Clements, October 1972).

³ Percent increase terms of 1.515 and 1.0111 are applied to slope and intercept terms respectively; after relations for hardwoods.

⁴ 0.80 = decimal percent of hazel crown coverage and 0.20 = decimal percent of "holes."

Table 4.--Stemflow, throughfall, and net precipitation equations for a 23 BA red pine, hazel, bracken fern forest, growing season conditions

Component	Equation ¹	$S^2_{y \cdot x}$	N	Source
Red pine stemflow	$(S_R) = -0.076 + 0.02 P$	0.003	80	Rogerson & Byrnes 1968
Red pine throughfall	$(T_R) = -1.02934 - 0.00422 P (23) + 0.97950 P$	.065	80	Rogerson 1967 ⁴
Hazel stemflow	$(S_H) = (1.5815)(0.001 T_R^{1.451})(2.0)(2.06 T_R^{-0.182}) -$		36	Clements 1971
Hazel throughfall	$(T_H) = 0.50 T_R + 0.50 (-0.27 + 0.94 T_R)$	.303 ²	27	Clements 1971
Bracken fern stemflow	$(S_B) = (2.6193)(0.034)(T_H)^{(0.873)}$	.021 ³	8	Clements 1971
Bracken fern throughfall	$(T_B) = -0.250 + 0.76 T_R$	.109	8	Clements 1971
Net precipitation	$(Net P) = 0.41 T_B + 0.59 T_R + S_R + S_H + S_B$	-	-	-

¹ P = gross rainfall; 23 = BA red pine (m²/ha); 1.5815 and 2.6193 = No. stems per ha : 10,000; 2.0 = mean height of codominant hazel stems (in m); 0.50 = decimal percentage of hazel crown coverage and "holes" in hazel crown; 0.41 = decimal percentage of bracken fern crown coverage; 0.59 = decimal percentage of holes in bracken fern canopy.

² Refers to equation in parenthesis only.

³ Refers to single stem equation (delete area factor of 2.6193).

⁴ Loblolly pine equation with .563 subtracted from intercept term. 0.563 derived from comparison of red pine and loblolly pine equations.

Specific equations that were used to calculate net snowfall under each forest type are shown in table 5.

To obtain the annual net precipitation, the following equation was used:

Table 5.--Seasonal net snowfall equations (In mm)

Forest	Maximum water content: equation ¹	$S^2_{y \cdot x}$	N	Source
24.3 BA Aspen	MP = 2.134 + 0.900 P	2.134	39	(²)
34.4 BA Jack pine	MP = -9.627 + 0.879 P	7.378	10	(²)
32.1 BA Red pine	MP = -9.627 + 0.879 P	-	-	(³)
23 BA Red pine	MP = -7.087 + 0.879 P	-	-	(³)
13.8 BA Red pine	MP = -4.547 + 0.879 P	-	-	(³)

¹ MP = The maximum water content occurring in the snowpack for a given year. P = The sum of standard snowage precipitation for the period between the time of the first snowfall to stay on the ground and the time of maximum snowpack water content.

² Verry, unpublished data. Based on 10 years of Mt. Rose snowtube measurements at 78 aspen points and 10 jack pine points on the Marcell Experimental Forest.

³ Bay, R. R., and D. H. Boelter, unpublished data. Exploration study of snow accumulation, snow disappearance, soil freezing and moisture regime in several types of northern Lake States forests. Final Progress Rpt, 1960, on file at the Northern Conifers Laboratory, Grand Rapids, Minnesota. Two years of maximum snowpack data under three stocking levels of red pine were similar to our jack pine data. Therefore we used our jack pine equations for red pine with appropriate changes in the intercept terms for the three stocking levels. Red pine data from Dils and Arend (1956) for snow depths showed a similar trend. These equations are also within the data range for snowpack water content given by Hansen (1969) at the 61 mm P level.

$$NP = \sum_{i=1}^n \text{net } P_i + MP \quad (3)$$

where:

net P_i = the amount of net precipitation per rainstorm

n = the number of rainstorms per year

MP = the total net snowfall

A year was defined as beginning on April 1 and ending on March 31. A rainstorm was defined as a rainfall event separated by at least 6 hours from another rainfall event. All of the net precipitation equations were applied to actual rain and snow records from the Marcell Experimental Forest in north central Minnesota (Ca. 47° 32'N, 93° 28'W). High, average, and low rainfall years were combined with high, average, and low snowfall years, respectively, to avoid possible confounding of forest comparisons. The resulting range of annual precipitation was identical to

the measured range of annual precipitation. There were periods of 2 to 4 weeks during each year when snow fell after the snowpack began to melt. I assumed that these snowfalls would be followed by above freezing temperatures and that net precipitation could be calculated best using the net storm rainfall equations.

Equations for dormant season hazel throughfall and stemflow in the red pine stand are identical to those of the aspen stand except that T_R replaces T_A and stems per hectare values are changed appropriately (table 1). The net storm precipitation equation for dormant season red pine stands is similar to that of table 3 except T_R replaces T_A and the crown coverage weighting factors are 0.50 and 0.50.

Growing and dormant season rainfall T , S and Net P equations for 13.8 and 32.1 BA red pine forests are identical to those for 23 BA red pine except as modified by basal area, stems per acre, and percent crown coverage.

All the equations for net rainfall components are applicable for gross rainstorms of 2-50 mm except the equation for aspen stem flow during the dormant

season which is applicable for 2-25 mm. Equations for maximum snowpack water content are applicable for seasonal gross precipitation from 60 to 220 mm.

Many studies in the literature do not list variances, data sets or sum of "independent variable" deviations. Therefore, a straightforward variance calculation for annual net precipitation totals is impossible. Other fundamental gaps in data, such as additional water losses between site and user makes a statistical treatment of secondary importance.

The net storm rainfall equations were used with actual growing season and dormant season rainfall data and summed to calculate the annual distribution of rainfall in the aspen and red pine forests. Data for an average rainfall year are shown in table 6.

The net storm rainfall equations were added to net seasonal snowfall equations for low, average and high precipitation years to give annual estimates of net precipitation (table 7). The total net precipitation data for aspen and red pine forests were used to construct the lines in figure 1.

Table 6.--Distribution of rain in four forests for an average precipitation year
(In mm)

Rainfall season and forest	:Stem- :flow	:Stem- :flow	:Stem- :flow	:Through- :fall	:Through- :fall	:Through- :fall	Net precipitation
	:tree	:hazel	:bracken	:tree	:hazel	:bracken	
Average growing season rain (460 mm)							
23 BA aspen	16	19	28	---	348	300	362
13.8 BA red pine	6	11	26	377	350	306	349
23 BA red pine	6	5	22	359	343	306	339
32.1 BA red pine	6	2	15	342	328	301	325
Average dormant season rain (175 mm)							
23 BA aspen	9	7	--	149	140	---	156
13.8 BA red pine	2	4	--	136	128	---	134
23 BA red pine	2	2	--	129	125	---	128
32.1 BA red pine	2	1	--	123	119	---	121
Average growing and dormant season rain (635 mm)							

Table 7.--Net precipitation under four forests in north-central Minnesota for low, average, and high precipitation years

Precipitation		No. of storms	Gross precip.	23 BA aspen	13.8 BA: red pine	23 BA: red pine	32.1 BA: red pine
LOW							
Rain	GS ¹	mm	41	272.3	200.3	190.8	185.9
		%		(100)	(73.5)	(70.1)	(68.3)
	DS ²	mm	39	207.8	182.2	150.4	144.2
		%		(100)	(87.7)	(72.4)	(69.4)
Subtotal		mm	80	480.1	382.5	341.2	330.1
		%		(100)	(79.7)	(71.1)	(68.7)
Snow		mm	25	61.0	56.9	49.3	46.7
		%		(100)	(93.3)	(80.8)	(76.6)
Total		mm	105	541.1	439.4	390.5	376.8
		%		(100)	(81.2)	(72.2)	(69.6)
AVERAGE							
Rain	GS	mm	47	459.5	362.4	349.2	338.8
		%		(100)	(78.9)	(76.0)	(73.7)
	DS	mm	27	175.0	156.1	133.9	128.2
		%		(100)	(89.2)	(76.5)	(73.3)
Subtotal		mm	74	634.5	518.5	483.1	467.0
		%		(100)	(81.7)	(76.1)	(73.6)
Snow		mm	34	121.9	111.8	102.9	100.3
		%		(100)	(91.7)	(84.4)	(82.3)
Total		mm	108	756.4	630.3	586.0	567.3
		%		(100)	(83.3)	(77.5)	(75.0)
HIGH							
Rain	GS	mm	45	477.5	381.0	367.0	355.6
		%		(100)	(79.8)	(76.8)	(74.5)
	DS	mm	26	241.0	221.0	197.0	188.2
		%		(100)	(91.7)	(81.7)	(78.1)
Subtotal		mm	71	718.5	602.0	564.0	543.8
		%		(100)	(83.8)	(78.5)	(75.7)
Snow		mm	33	208.3	189.5	178.8	176.3
		%		(100)	(91.0)	(85.5)	(84.6)
Total		mm	104	926.8	791.5	742.8	720.1
		%		(100)	(85.4)	(80.1)	(77.7)

¹GS = Growing season

²DS = Dormant season

APPENDIX IV--DOCUMENTATION FOR BLACK SPRUCE EQUATIONS

Stemflow and throughfall were measured in two black spruce stands on the Marcell Experimental Forest in 1969 and 1970. In these stands, which grew on organic soils, there were not any tall shrubs or forbs.

The 73-year-old stand had a total basal area of 30.1 m²/ha on 3,029 stems. The 62-year-old stand had a total basal area of 26.2 m²/ha on 8,411 stems. Average dominant height in the older stand was 15 m and 11 m in the younger stand. Crown coverage in both stands was approximately 68 percent.

Stemflow was measured on a 0.016 ha plot in each stand from 12 trees. Throughfall was measured in 25 randomly located rain gages. There was no difference in data between the two stands ($P \geq 0.10$).

$$S_{BS} = -0.004 + 0.001 P \text{ mm } S_{y \cdot x}^2 = 0.0004 \text{ mm} \\ N = 47$$

$$T_{BS} = -1.600 + 0.934 \text{ mm } S_{y \cdot x}^2 = 0.025 \text{ mm} \\ N = 78$$

where:

S_{BS} = black spruce stemflow
 P = gross rainfall
 T_{BS} = black spruce throughfall

A seasonal net snowfall equation was derived from 10 years of Mt. Rose snowtube measurements at 39 points under six stands on the Marcell Experimental Forest. The six stands averaged 23 m²/ha of total basal

area on 1,860 stems. Average dominant height was 13.4 m, average age 90 years, and average crown coverage 51 percent.

The seasonal net snowfall equation was:

$$MP = -1.448 + 0.782 P \text{ mm } S_{y \cdot x}^2 = 2.397 \\ N = 19$$

where:

MP = the maximum water content occurring in the snowpack
 P = the sum of standard snowgage precipitation

The black spruce equations above were solved for low, average and high precipitation year to give the net precipitation values in table 8. Stemflow values were only a trace on an area basis; therefore, the net precipitation values in table 8 are simply black spruce throughfall. These values are similar to the red pine values without shrub and bracken fern components. Thus, they may be applicable in evaluating conversions on uplands where black spruce stands have a shrub component.

Table 8.--*Net precipitation under black spruce on organic soil with no tall shrubs or forbs*
(In mm)

Precipitation: component	Low year		Average Year		High Year	
	Gross	Net	Gross	Net	Gross	Net
Rain	480.1	335.9	634.5	488.2	718.5	568.5
Snow	61.0	46.5	121.9	94.0	208.3	161.5
Total	541.1	382.4	756.4	582.2	926.8	730.0

Verry, Elon S.

1976. Estimating water yield differences between hardwood and pine forests: an application of net precipitation data. USDA For. Serv. Res. Pap. NC-128, 12 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Provides a means of assessing the impact of hardwood-pine conversions on water yield. Assembles many interception studies and applies them to evaluate net precipitation under red pine and aspen forests.

OXFORD: 116.11:212.1:(776). KEY WORDS: forest conversions, streamflow, aspen, red pine, black spruce, interception, forest hydrology.

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A COMPUTER SIMULATION OF FULL-TREE FIELD CHIPPING AND TRUCKING

DENNIS P. BRADLEY, FRANK E. BILTONEN, AND SHARON A. WINSAUER

CONTENTS

Purpose	1
What the Simulator Is and Does.	1
Description of the Simulator.	2
Using the Simulator	11
What Problems Can This Simulator Examine?	11
Summary	12
Appendix.	12

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A COMPUTER SIMULATION OF FULL-TREE FIELD CHIPPING AND TRUCKING

Dennis P. Bradley, Frank E. Biltonen, and Sharon A. Winsauer

Loggers and wood users have shown continuing interest in full-tree field chipping from its conception, but its complexity, high costs, and mill use problems have discouraged acceptance. A key factor in the slow pace of adopting this or any other new harvesting technique is the fact that "trial and error" is the dominant form of learning how to use new harvesting methods. This may have been adequate before but certainly not now. Loggers, landowners, and consumers all lose when logging methods are inefficient. Better methods of planning to improve harvesting efficiency are urgently needed.

PURPOSE

This paper describes the principal features of a computer simulation of a full-tree chipping system that can help loggers increase production and lower costs. The purpose of this work, in addition to improving the efficiency of field chippers, is to demonstrate the flexibility and realism that can be achieved with simulation for the improvement of any harvest system.

Only the larger companies and loggers have the resources to put simulation to immediate use, but the spin-off of improved techniques and methods will benefit all loggers. Future publications will include a more detailed description of the model as well as specific examples of how this simulator has been used by loggers to direct changes in their operations.

Simulation or modeling is actually an old tool: the value of model bridges and aircraft is familiar to all. However, a computerized abstraction of a harvesting system seems quite different. How can numbers in a calculator express the complex relations between men, machines, and work rules? Although the process sounds mysterious and uselessly hypothetical, computer simulation has nevertheless proved to be an extremely powerful approach to system design in many other problem areas. And there is every reason to expect a similar contribution to logging.

WHAT THE SIMULATOR IS AND DOES

This simulator is a computer program whose instructions represent (a) the resources used by the real system, such as men and machines; (b) the actions performed by these resources; and (c) the operating rules that determine what will happen next when decisions are necessary. In addition, a simulated clock provides the background in which all the resources, actions, and rules interact.

The real system is simulated by telling the computer to symbolically set the resources to work for a desired period of simulated time. At the end of this simulated time, which may represent months of real activity, the computer tells the user how the model performed. For example, how much wood was produced, how much did it cost, where did one machine interfere with another, etc.? This report or history of the model is the payoff. If the user is confident

that the model is a realistic copy of the real system, (more will be said about model realism later) he can draw conclusions about how to operate the real equipment. Should he add or remove equipment, or change operating rules, or alter work schedules?

Because computers are so fast, time, in effect, can be compressed and months or years of activity can be summarized in a few milliseconds of computer time. And therefore, many system alternatives can be examined realistically in a fraction of the time and cost required for an actual field test. Simulation does not eliminate the need for field testing but a great deal of wasted effort can be avoided.

The simulator is written in GPSS/360, an extremely popular and powerful general purpose simulation language. Developed by IBM,^{1/} this language has now been implemented on the machines of several manufacturers.

¹ International Business Machine Corporation. General Purpose Simulation System V Users' Manual. SH20-0851-1. White Plains, New York. 422 p. Illus. 1973.

DESCRIPTION OF THE SIMULATOR

The simulator duplicates the major features found in a real system (fig. 1):

1. A stand of trees.
2. Feller-bunchers.
3. Skidders.
4. A chipper with loader.
5. Trucks and vans.
6. One or two optional setout trucks.
7. Mill yard scale and chip dumper.
8. Other trucks (provide realistic competition at the mill scale and dumper).
9. A master timer.

The following descriptions of each segment include the processes being simulated, the data to be provided by the users, the kinds of events that result in decisions, and the quantifiable criteria for making each decision.

A realistic correspondence between the real system and its model is essential in establishing a user's confidence in the model. On the other hand, it should also be apparent that not all detail is equally relevant. For example, we feel that the feller-buncher's travel and harvesting actions in this model are very realistic.

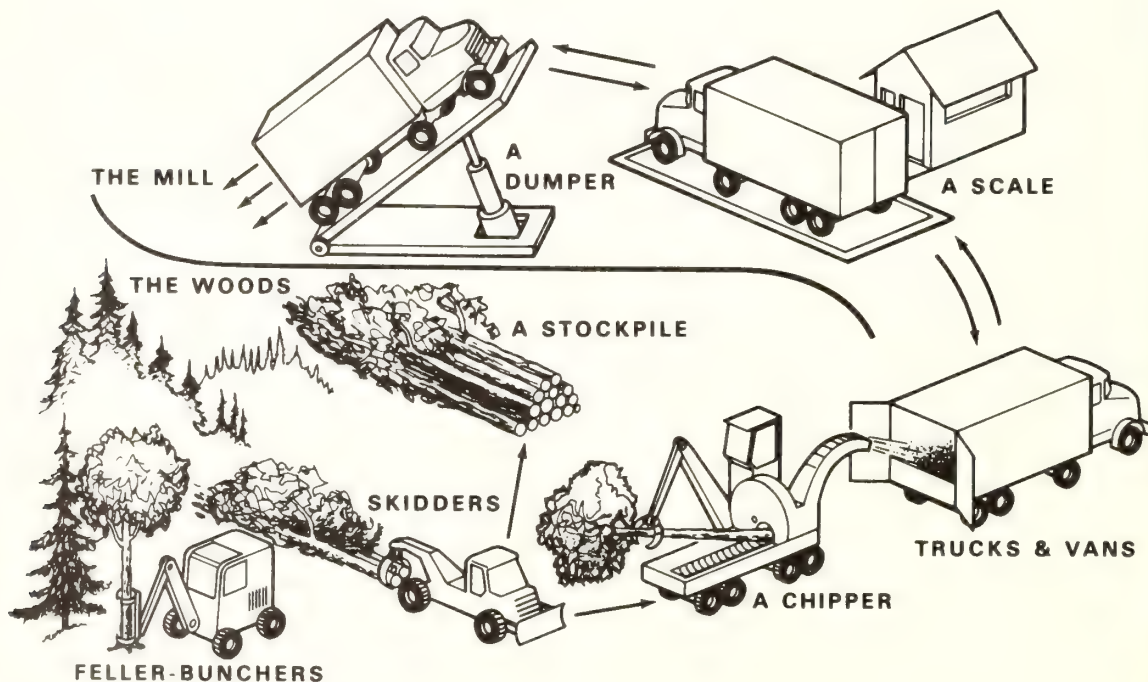


Figure 1.--The full-tree field chipping system.

the feller-buncher travels to each tree, fells it, and leaves it or carries it along. Each tree has a unique location, diameter, and volume. Average felling rates or average tree sizes or average travel distances are not used. Yet, the model does not include refueling stops. In other words, we felt that unique tree positions and volumes were very important details but that refueling was not.

The same point can be made for every other segment; we feel that we have included the relevant realistic detail. The degree of detail described here and how well it fits a user's own conceptions and needs will determine, in large part, how useful this model will be for him. In any event, we hope that the general approach described here will be valuable. Certainly, the simulator can be modified if necessary.

This simulator has been designed to be as independent of specific machines as possible. That is, the nature and the order of the processes performed by each machine are the same regardless of the brand name or size of the machine. Differences in machine speeds and capacities can then be changed by the user to reflect the specific machines he wishes to serve.

Feller-Bunchers

Feller-Buncher--Stand Interaction

The number of feller-bunchers, stand character, and terrain are the main factors affecting feller-buncher production.

The feller-bunchers harvest a stand based on an arbitrarily selected basic plot of 1 or 2 acres. The basic plot data, provided by the user, consists of unique tree locations (x and y coordinates) and volumes for each tree in the stand. Prior to the simulation, the user prepares a two-dimensional plot of the test stand and manually selects a tree felling order for every tree in the basic plot. This felling order is selected in a way, logically and practically similar to the order an actual feller-buncher would use. Although this felling order is followed precisely by all feller-bunchers, bunch composition and the actual travel path are

established independently and may differ considerably. This process is described below.

To achieve a harvested area of the desired size for simulation, since 1 or 2 acres may not be an adequate test, the basic plot can be harvested as many times as necessary. The total harvest area desired is divided equally among the feller-bunchers into as many basic plot units as necessary. (This process of harvesting the same plot many times is dictated primarily by computer core memory limitations. It may be possible to replace it with one large plot if the data and core space are available.)

Thus, each feller-buncher will harvest this basic plot several times in order to achieve the desired harvest area for all feller-bunchers. A Basic plot is hereafter called a subregion. The total number of subregions assigned to each feller-buncher is called a region.

This segment permits a user to choose two basic methods to prepare bunches for skidding. First, trees may be cut and carried one at a time to a bunch on the ground until the desired bunch size is reached. Second, several trees may be cut and carried along in an accumulator. When full, this accumulation or bouquet will be deposited on the ground as a complete bunch by itself, or it may become a partial bunch to which other bouquets are added. Desired bunch size, accumulator limits, feller-buncher to tree distance limit, and partial bunch to tree distance limit, can all be set by the user.

For the feller-buncher and all other segments, the times consumed in carrying out the specific processes must be provided by the user. An important point to note here is that all segments in the model can accommodate not only constant data but also data with random variation, or any mixture of the two at the user's discretion. For example, the user may decide to have each feller-buncher travel at precisely the same speed all the time or he may permit machines to vary their speed at random, around some mean speed. This ability to reproduce random variation is extremely important in achieving realism, although it also raises some data collection and analysis problems, to be discussed later.

Another feature of this model that requires emphasis is that individual trees maintain their identity from the time they are cut until they are chipped and blown into the van. This consistency is extremely important but has not been a part of other harvesting simulators.

Feller-Buncher--Feller-Buncher Interaction

If by chance a feller-buncher completes the felling and bunching of all assigned subregions, it may assist any other feller-buncher who has not completed all of his. However, the subregion or basic plot is the smallest unit that a feller-buncher can work in; that is, only one feller-buncher is allowed in a subregion at a time while several feller-bunchers can work in the same region.

When all subregions and regions have been felled, the feller-bunchers quit; presumably they go to another logging chance independent of the area under simulated harvest.

Each bunch, when completed by the feller-buncher, possesses all the information necessary to affect skidding and chipping operations on it. For example, each bunch includes 1) a record of each individual tree volume as well as their sum; 2) its skid distance to the landing; 3) the feller-buncher that produced it; and 4) the subregion in which it was felled.

Feller-Buncher--Skidder Interaction

One additional feature is provided in the case of a skidder catching up to a feller-buncher and deciding (these rules will be described later) to take the partial bunch, that is, a bunch not complete in the feller-buncher's opinion. Of course, if the skidder takes this partial bunch, the next tree felled or the next bouquet to be completed will be the next partial bunch.

Skidders

Skidders convey complete bunches (complete in their opinion) from the bunches' locations in the woods to the landing and chipper. Numbers of skidders, skid distances, terrain, and bunch size are the principal factors affecting skidding production.

Skidder--Feller-Buncher Interaction

The user must initially assign one or more skidders to work with each feller-buncher. Each skidder can be thought of as following a trail of completed or partially completed bunches unique to its feller-buncher assignment.

As long as the skidder does not catch up to the feller-buncher, that is, as long as fully completed bunches exist on its unique trail, the skidder stays with its initial feller-buncher. However, if it does catch up a change in feller-buncher assignment may be necessary. To provide the model with this power, a set of tests is available to the user.

When a skidder catches up, it checks to see if the partial bunch is big enough to (a) *take* as it is, (b) *wait* for it to get bigger, or (c) *look* for work elsewhere with another feller-buncher. Whether the bunch is big enough determines the change, and the user can set these limits as he sees fit.

Skidder--Chipper Interaction

Once at the landing, each skidder has more decisions to make. There are two places to take the wood--directly to the chipper, or to the stockpile. The reasons for the two spots are:

1. If the skidders begin work before the chipper arrives on the job, they must have a place to deposit bunches.
2. After the chipper is on the job, the limited capacity of the area within reach of the chipper's integral loader may require a skidder to wait to deposit a bunch directly at the chipper.

Since the whole objective is to eliminate inefficiency, the model provides two sets of rules to achieve efficient routing. These rules can be changed by the user to find the best rules for each situation.

Case I--A skidder is approaching the landing with a bunch and the chipper is on the job (fig. 2). The skidder can either (a) deposit bunch at chipper or (b) deposit bunch in stockpile. There are two costs dependent on the decision:

1. If deposited at chipper, the skidder may incur waiting costs.

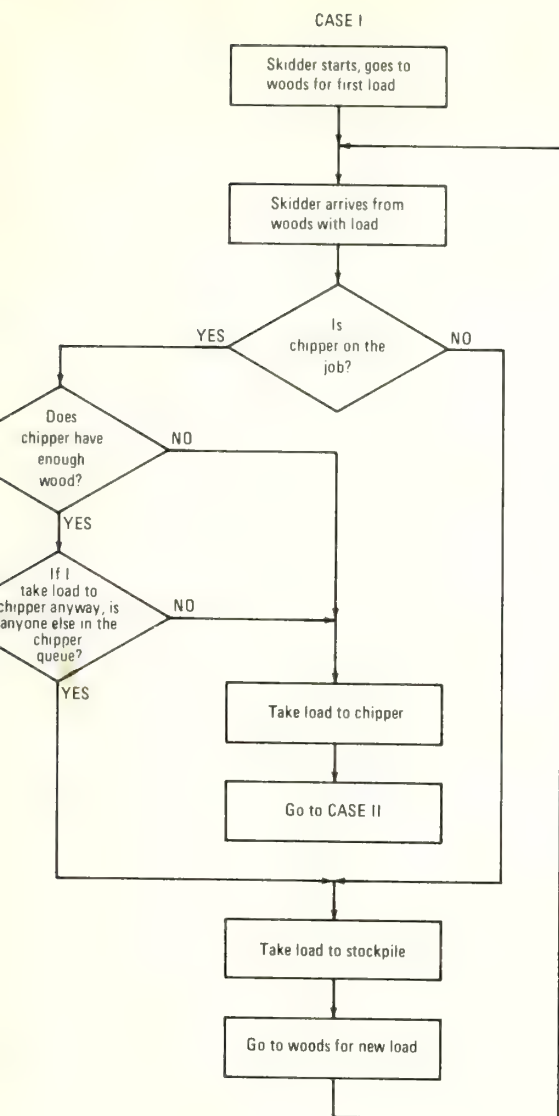


Figure 2.--Skidder logic employed for Case I.

If deposited at the stockpile, the skidder will *unavoidably incur* double handling costs.

A skidder asks two questions to reach a decision. First, does the chipper need wood? If it does, take the bunch to the chipper. On the other hand, even if the chipper does not immediately need wood, the skidder would still like to drop its bunch

at the chipper to avoid unnecessary stockpiling if the estimated skidder wait is short. Thus, the second question is: are other skidders ahead of him to cause excessive waiting? If not, take the bunch to the chipper. Otherwise, take the bunch to the stockpile. The minimum amount of wood needed by the chipper and the limit on the number of skidders waiting to drop bunches at the chipper can be changed to arrive, by repeated trials, at the correct tradeoff.

Note in fig. 2 that when a skidder drops a bunch at the stockpile it categorically goes back to the woods for a new bunch.

Case II--From Case I, the skidder has dropped its bunch at the chipper (fig. 3). It can either (a) get a new one from the woods, or (b) bring a bunch from the stockpile. Three potential costs are associated with this decision:

1. If the skidder goes back to the woods, the chipper may run out of wood.
2. If it decides to bring another bunch from the stockpile just as another skidder is coming from the woods, it might cause this other skidder to drop its bunch in the stockpile with a net loss of effort due to (a) double handling two bunches instead of one and (b) a disruption of skidding operations.

The skidder asks three questions to reach a decision:

1. Does the chipper still need wood?
2. How many other skidders are waiting to drop bunches at the chipper?
3. Is any other skidder "near" the landing?

The minimum amount of wood required by the chipper, the limit on the number of skidders waiting at the chipper, and distance from the landing at which skidders on the landing can "see" an approaching skidder, can all be changed to test their effect on skidding costs. Figures 2 and 3 are not complete in detail but serve to show the logic employed.

When all bunches have been skidded, one or more skidders are assigned the job of emptying the stockpile for the chipper or the chipper can be brought to the stockpile.

CASE II

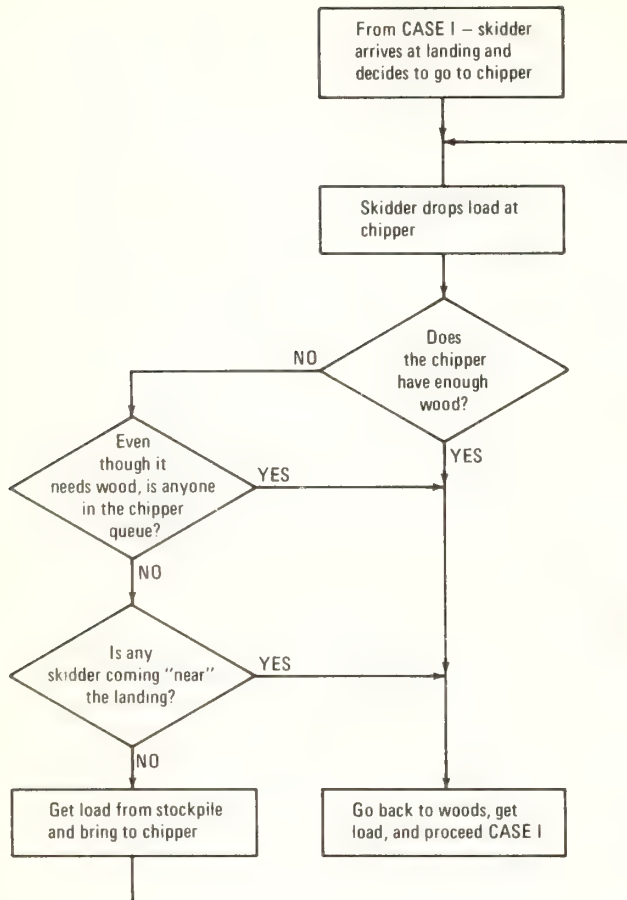


Figure 3.--Skidder logic employed for Case II.

Chipper

This segment duplicates the operation of a portable chipping machine with an attached or separate loader. Chipper production is dependent primarily on tree size, loader capacity, chipper capacity, and the number of vans that can be positioned in front of the chip spout.

Chipper--Skidder Interaction

Bunches of trees are brought by skidders to an area within reach of its loader where the bunches are "broken up" by the loader to construct chipper loads. The size of each load is dependent on the capacity of the loader's grapple and the chipper's mouth and the user can specify this load size in terms of number of stems and/or total volume.

After picking up the load, the loader places it on the feed conveyor and assists

the chipper feeding process. When this assistance is completed, the loader gets another load from the trees in the buffer. The simulator records chipper delays due to the skidders not bringing enough wood.

Chipper--Van Interactions

The number of slots for empty vans, dependent on the size of the landing area, and on the flexibility of the chipper spout, is set by the user.

Once chipped, the load's volume is added to the van and a test is performed to see if the van is filled. If not, another load is chipped. When the van is filled, it is closed, the spout is moved to the next empty van and chipping resumes. Of course, if there are no empty vans in slots, or if there are no more trees in the chipper buffer, chipping will stop and the delay will be recorded.

Trucks, Vans, and Setout Trucks

This segment has the job of moving full vans to the mill. The number of trucks, setout trucks, vans, and hauling distance are the major factors affecting productivity.

Three different trucking situations are identified in this model.

Situation 1.

- There are no terrain and road problems; highway tractors with vans can drive directly to the chippers without assistance.
- Setout trucks for handling empty and full vans are not required, because either
 - There are *no* extra vans or
 - There are extra vans *but* the number of slots at the chipper equals or exceeds the total number of vans.

Situation 2.

- There are still no terrain or road problems; highway tractors can get to the chipper without assistance, but
- One or more setout trucks *are required some of the time* because both of the following conditions are true:
 - There are extra vans *and*
 - The number of slots at the chipper is less than the total number of vans.

situation 3.

. Terrain and/or road problems prohibit the highway trucks from bringing empty vans to the chipper. They must drop empties and pick up full vans a considerable distance away.
One or more setout trucks must therefore do all the work of moving empty and full vans to and from the chipper. Setout trucks in this situation are probably specially modified dozers or skidders with a fifth wheel.

The three situations are distinguished primarily on how any setout trucks, if used, interact with the highway trucks. In situation 1, a setout truck is never used; in 2, they are used only when necessary because the incoming highway trucks can do most of the handling; and in 3, they are used exclusively for van handling. In addition, the trucking segment distinguishes between a chipper having one slot in front of the spout and two or more slots.

The following detailed description of chipper, van, and setout truck interactions in two or more slots seems to concentrate on situation 2, but it works the same for situation 1. Situation 3 can also be handled but with slight modification.

Chipper and Setout Truck Logic for Situation Two or More Slots

As already summarized, highway trucks have no trouble reaching the chipper, and one or more setout trucks are required because there are more vans than trucks, and the space for vans at the chipper is less than the total number of vans.

Thus, an area must be provided within a short distance of the chipper for incoming trucks to drop empty vans when no slots at the chipper are open.

Also, a similar (if not the same) area must be provided for full vans completed by the highway tractors return from the mill. Obviously, this movement of empty and full vans in the absence of highway tractors is done by a setout truck (SOT) in order to keep the chipper working and to reduce truck turnaround time.

The HT's and the SOT's cooperate to avoid unnecessary van handling. If possible, incoming HT's drop empty vans directly in a slot at the chipper and, secondly, they also

try to pick up a full van or attach themselves to a partially full one in another slot.

Correspondingly, but with the subservient role, the SOT's move empty vans only when the chipper needs one and remove full vans only when no HT's are around. They never hook up to a partially full van.

At the instant an HT reaches the landing with an empty van, the location of empty slots and full or partially full vans is determined. Based on this status, the complete route of this HT into and out of the landing is determined at this time. Then it proceeds to drop its van somewhere and to pick up a full one or attach itself to a partial van somewhere else. Or perhaps the HT may remain attached to its original van until a slot is open and its van can be filled. But in any event, once it is on its way into the landing, no other HT or SOT can disrupt or change its route. This is done by permitting the HT to "reserve" the best path for entering and leaving the landing that it saw at the outset.

The purpose of SOT's is to increase the productivity of both the chipper and the HT's while minimizing their own work and interference. They move empty vans to the chipper from the empty van storage area and full ones from the chipper to the full van storage area only (1) when there are no HT's around and (2) when requested to by the chipper.

As described above, the HT's will always try to drop their empty vans directly in a chipper slot and will always try to pick up a full or partially full van at the chipper.

By taking empty vans to the chipper only when the chipper is about to run out of empties, the SOT's allow these slots to remain open as long as possible for the HT's. This minimizes the double handling of empties.

By picking up full vans at the chipper only when requested to do so, SOT's allow the returning HT the maximum opportunity to get a full van right at the chipper. This minimizes the double handling of full vans.

Truck and Setout Truck Logic for Situation 2--One Slot Only

When there is only one slot, the trucking segment becomes a bit simpler, the

setout truck segment becomes more complex, and their interaction changes profoundly. For example, when there are two or more slots at the chipper, SOT's never hook up to a full van in a slot unless requested to do so by the chipper. The SOT's leave the full van there as long as possible in order to give an incoming truck a chance to haul it away. Similarly, they leave the slot open as long as possible for a truck and only bring empty vans when requested by the chipper. In addition, they always drop empty vans in the slot and *get out of the way*. These choices are relevant, because the chipper can keep producing while the SOT brings empties to or removes full vans from the other slots.

However, when there is only one slot, SOT's must not wait until the van is full before reacting. A SOT must be ready to remove this full van as quickly as possible and get another empty in its place because the chipper will be idle until it does (a costly alternative). Therefore, when only one slot exists, SOT's *stay attached* to the empty van after moving it into the slot. Then, when the van is filled, the SOT can immediately move it to the storage area and get another empty.

By staying attached, a single SOT can get the chipper producing in much less time than if it first had to move in and hook up. If a second SOT is available, efficiency can be improved further by having the extra SOT standing by with another empty ready to move in, as soon as the first SOT removes the full one.

However, what if a truck shows up at the landing while the SOT is attached to the single partially full van and there are no other full vans ready? This problem never occurred before under the SOT's rules for two or more slots.

In this new case, the incoming truck orders the attached SOT to disconnect from the van in the slot, while dropping its own empty van in the storage area. The truck then hooks up to the partially full van in the slot.

An additional feature of this modification for one slot occurs when the slot is open but a full van is also ready at the storage area. In this case the truck has the option of placing the empty van in the slot and waiting until it is full, or of dropping the empty van in the slot and

picking up the already full van. The truck can compare the two series of estimated times in making this decision.

Other Trucks

This segment is included in the simulation to recreate the competition that captive chip trucks encounter at the mill yard. Regardless of how efficient the woods chipping operation is, its trucks are not the only ones using the mill yard. The user specifies not only how often other trucks arrive at the mill yard, but what proportion are chip trucks or roundwood trucks. As in the real world, other trucks and the captive chip trucks are served on a "first come" basis. But while all trucks compete for the service of the scale, only "other chip trucks" compete with the captive chip trucks for the use of the chip van dumper.

Other trucks' "inter-arrival times," that is, the time that elapses between the arrival of one "other truck" and the next, and the other time data must be gathered from the user's mill yard records at the scale or mill yard gate.

Master Timer

In any complex system, timing plays an important role--when does the system start, does each part start at the same time, when should each part stop working, do scheduled interruptions play an important part in the system, what about unscheduled interruptions, are multiple shifts in effect, and are there situations requiring overtime?

In this system simulator, we have concentrated on three principal areas: (1) system start-up, (2) working day length or production quota, and (3) exceptional situations to prolong the working day.

System Start-up

Except for the fact that segments of this system must perform in sequence to get the wood to the mill, the starting times of each segment are optional. The feller-bunchers start first, but the user can choose the number of days or hours at which each subsequent segment begins work. For example, feller-bunchers may start on Day 1, skidders on Day 3, and the chipper on Day 4. A day counter in the master timing segment triggers the initial start-up of each machine segment.

Although the master timer controls the daily start cycle, each segment decides by itself when to stop. This stopping cue may be given by having a specific machine segment refer to the clock to see if the desired time has been reached or if a desired production quota has been achieved. Here, too, the user can choose the hours or quotas for each segment independently. If desired, interruptions for coffee, lunch, or preventive maintenance can be scheduled.

Exceptional Situations

In some situations overtime may be required. Because of the unusually long hauling times or other sources of unplanned delays, such as long waiting lines at the scale, the system may have to work longer to insure that trucks do not spend the night on the landing. For example, assume that trucks will not return to the landing or another load when they leave the scale empty after 4 p.m. Before 4 p.m., they usually have enough time to return to the chipper for one last load for the night. But because a particular return trip to the woods takes longer than expected, it arrives at the landing after the system could ordinarily quit. In this situation, the system knows the truck is on the way, and it will work overtime until a full van is ready. Many other options are possible, including daily work quotas.

Delays Due to Machine Breakdown

This model description has concentrated on delays caused by machine interactions but ignored delays caused by machine breakdowns. That is, all machinery is assumed to work perfectly. However, if the user has machine breakdown data, it can easily be included. At a minimum, a user needs to know how often specific machines fail and how long the repairs take. Given this data, at the start of each skidder trip, for example, the skidder would sample a "breakdown occurrence distribution." If no breakdown is due to occur this cycle, the skidder would be allowed to complete it. If a breakdown is due, the skidder transaction would then sample a "breakdown duration distribution" which would determine how long the machine would be out of operation.

Finally, this simulator gives a daily report of system production, cost, and interaction for each component. An example of the report (see Appendix) shows how much a system consisting of three feller-bunchers, three skidders, one chipper and loader, three trucks, six vans, and one setout truck, produced while operating in a stand having 2,915 cubic feet per acre and 200 trees per acre, etc. Keeping in mind the statistical problems to be discussed shortly, the user should interpret this information in much the same way that he would examine the records of a real system. The main difference is that the model's summary is probably a hundred times more detailed than any real system.

Simulator Data Requirements

Stand data--Diameters, heights, volumes, and locations for each tree are necessary. There are a number of ways to acquire this data varying from field measurement to the use of computer generated data.

Machine speed--is the time required to travel or process. These times may be as simple as a constant or as involved as a function of many variables--terrain, distance, tree or load size. In any event, the simulator can take whatever data is available from constants, estimates of a mean and a variance, equations, or frequency distributions. In most every case, however, machine speeds can be expected to vary--even under fairly constant conditions--and the simulator can handle this very important facet of real systems.

Machine capacity is the maximum size load a machine can handle. In contrast to the case of machine speeds, the simulator must be provided with fairly rigid machine capacities. Providing a maximum limit in volume or stems does not mean that each load will always achieve the limit. For example, if the feller-buncher's accumulator could take 15 cubic feet more but the next tree has 50 cubic feet, the feller-buncher does not add this tree to the bouquet but drops what it has and starts to create another.

Decision making--The simulator must decide, as a real system does, what happens next in ambiguous situations. These decisions

take place within a machine or process's own task or at the point where different machines interact. For example, one or more features of the system (a feller-buncher's current bunch size) is compared to some standard (the desired bunch size to meet the skidder capability) in order to decide what to do next (get another tree for this bunch or start another bunch).

Data Needed for the Stand and Each Segment

Any unit of measurement can be chosen by the user. The current program uses time in centiminutes, distance in feet, area in acres, volume in cubic feet, and machine costs in dollars per machine hour.

1. Stand data.
 - a. Tree location in X and Y coordinates.
 - b. Tree volume.
 - c. Basic plot size.
 - d. Total harvest area desired.
 - e. Area to be harvested by each feller-buncher.
2. Feller-buncher.
 - a. Number of feller-bunchers.
 - b. Travel-empty speeds.
 - c. Travel-full speeds.
 - d. Shear speed including approach.
 - e. Drop speed.
 - f. Accumulator volume limit.
 - g. Accumulator stem limit.
 - h. Bunch volume limit.
 - i. Bunch stem limit.
 - j. Maximum travel distance limit.
 - k. Machine and labor costs per hour.
3. Skidding segment data.
 - a. Interaction with feller-bunchers.
 - (1) Number of skidders.
 - (2) Travel-empty speed.
 - (3) Travel-full speed.
 - (4) Position and grapple speed.
 - (5) Drop speed.
 - (6) For a partial bunch.
 - (a) "Take it" volume limit.
 - (b) "Wait for it" or "attempt to switch to another feller-buncher" volume limit.
 - b. Interaction with chipper.
 - (1) Minimum volume needed at the chipper to keep it from running out before another skidder arrives.
 - (2) Maximum number of skidders waiting at chipper before the next skidder is sent to the stockpile.

- (3) Maximum distance that other skidders can be seen from the landing.
- (4) Machine and labor costs per hour.

4. Chipping segment.
 - a. Loader speed including grapple, lift, swing, and feed assist.
 - b. Chip spout moving speed.
 - c. Number of slots for vans.
 - d. Maximum number of stems in desired load.
 - e. Maximum volume of stems in desired load.
 - f. Machine and labor costs per hour.
5. Trucking segment.
 - a. Number of trucks.
 - b. Number of vans.
 - c. Highway trucking speed--empty.
 - d. Highway trucking speed--loaded.
 - e. Van connect and disconnect time.
 - f. Van closing time.
 - g. Van capacity.
 - h. Number of setout trucks.
 - i. Highway and setout truck speeds on the landing.
 - j. Morning truck scheduling.
 - k. Machine and labor costs per hour.
6. Master timing and production summary segment.
 - a. Number of days to simulate.
 - b. Time lag for skidder start-up.
 - c. Time lag for chipping and trucking start-up.
 - d. Length of normal work day or daily trip quota.
7. Other trucking segment.
 - a. Inter-arrival schedule for other trucks at the mill scale.
 - b. Proportion of other trucks carrying chips.
8. Mill yard.
 - a. Number of scales.
 - b. Number of chip-van dumpers.
 - c. Number of roundwood unloaders if required for realism.
 - d. Truck weighing speed.
 - e. Chip-van dumping speed.
 - f. Roundwood truck unloading speed.
 - g. Truck speeds on the mill yard.

Data Collection Problems

The stand and time study data gathered by the user can be as simple or complex as desired, or as time and budget permit. But the adequacy of data is a complex problem and only general considerations will be touched upon here.

The results generated by the simulator can be no better than the data going in; accurate data is obviously important. On the other hand, limited time and money force the user to be selective. But what criteria should he use?

Two factors are important. First, the random variation that characterizes all processes can result in statistical sampling problems. Secondly, some aspects of the system have more impact than others on efficiency. These two factors interact. For example, a large error in estimating the time to move the chip spout from one van to another will probably not have much effect on system productivity, whereas a very small error in estimating skidding time per 100 feet may have a profound effect. The user must therefore strike a difficult balance among accuracy, precision, relevance, and budget.

USING THE SIMULATOR

The general process of developing and using this simulator to improve a real logging system consists of several steps. We have already outlined the need to choose a relevant degree of detail in the model that not only corresponds to the real world but also to the user's needs. The choice of detail is largely intuitive but is a key step in establishing a user's confidence in the model's inherent reasonableness.

In the next step, the user must test the simulator on an actual logging operation. This test is required to detect errors in either concept or model. That is, the user's concept may have been inaccurate; if so the model would be incorrect as well. Or the concept may have been correct but was not translated into a correct model.

Finally, the user can proceed to cautiously test different changes, first with the model and then with the actual equipment. At best, simulation is an evolutionary process. That is, while it may be possible to arrive at the best system by making several major changes at once, it should be clear that simultaneous changes can be confusing.

We have already mentioned that a realistic simulator allows random variations to occur during some, if not all, machine functions. Each separate machine function is in itself variable, and the whole chipping

operation may comprise 20 to 30 such functions operating simultaneously. To find the effect of changing a single function among all these interacting functions would be impossible without simulation.

For example, suppose a logger wants to see what effect adding another skidder has on production. Without simulation and using "trial and error", he uses the extra skidder for one or more days. He then compares production before and after using the extra skidder and asks whether the change was worth it. But no matter what numbers he compares, he has the nagging feeling that some unknown difference in weather, stand factors, attitudes, or a hundred other reasons, may have been the real cause for the observed difference. By trying his idea first on the simulator, however, the logger can even harvest the identical stand of trees twice; once with the usual number of skidders and the second time with the additional skidder. Because nothing else was changed, the difference in results can be attributed to the extra skidder.

But there are still complicating issues. Because random variation within limits is permitted, in the model as in the real world there is always the possibility of getting a bizarre series of random events. Thus, the user must also ask if each series was truly representative of the real system. To answer this question, the user can employ a variety of rigorous statistical techniques. These methods allow one to compare the variation within a given system, or between two or more different systems, in order to detect any real differences.

WHAT PROBLEMS CAN THIS SIMULATOR EXAMINE?

Computer simulation allows one to realistically manipulate a system in ways previously impractical, if not impossible. The following selection gives some idea of the tremendous range of factors that can be varied in simulation to learn their effects on the production and cost.

1. Stand characteristics.
2. Machine numbers and sizes.
3. Felling patterns.
4. Skidding patterns.
5. Acreage harvested per landing setup.
6. Truck scheduling.
7. Work day length.

8. The work rules affecting:
 - a. Skidder--feller-buncher interaction.
 - b. Skidder--chipper interaction.
 - c. Chipper--loader interaction.
 - d. Chipper--truck, van, and setout truck interaction.
9. The interaction of all of the above.

SUMMARY

Full tree field chipping is receiving a great deal of interest because of its many benefits, but its complexity, high cost, and mill use problems have discouraged acceptance. Using computer simulation, however, one can realistically analyze such complex harvest systems in a fraction of the time and cost of experimenting with real equipment. And as a result it is often possible to increase profits, reduce logging waste, allocate each tree to its best use, improve equipment design, and conserve fuel.

APPENDIX

Report Generated for One Day of a Possible Simulated Operation

I. STAND CHARACTERISTICS

30.00	Acres, total area to be harvested
2915.00	Cu. ft., average total volume per acre
9.53	Inches, average d.b.h.
65.00	Feet, average tree height
14.76	Feet, average tree spacing
200.00	Average number of trees per acre

II. SYSTEM CHARACTERISTICS

A. Feller-Bunchers.

3. Machines

Machine Limitations

The accumulator-shear can hold up to 50.0 cu. ft. or 5 stems, whichever comes first.

If the next tree is more than 50 feet from the feller-buncher, it is too far away to include in this bouquet.

If the next tree is more than 75 feet from the partial bunch, it is too far away to include in this bunch.

Bunch limitations dictated by skidder capacity.

The feller-bunchers try to achieve at least 100.0 cu. ft. or 10 stems in each bunch, whichever comes first.

B. Skidders

3. Machines

Interactions with feller-bunchers. When a 'catch-up' occurs, the skidder checks the partial bunch on the ground.

If the partial bunch has 75.0 cu. ft. or more, skid it as it is.

If the partial bunch has 50.0 cu. ft. to 75.0 cu. ft., wait for it to get bigger.

If the partial bunch has less than 50.0 cu. ft., attempt to switch to another feller-buncher.

Interactions with chipper.

Should the skidder take the bunch direct to the chipper or to the stockpile?

If at least 15 trees are within chipper's reach or with other waiting skidders, take bunch to stockpile.

If 2 or more skidders are already waiting at the chipper take the bunch to the stockpile.

C. Chipper--Loader

The loader can take up to 35 cu. ft. or 5 stems, whichever comes first.

Interactions with the setout truck. Setout truck is used only when no highway trucks are around, and only when the chipper requests that a full or empty van be moved.

Setout truck brings an empty van if more than 2 slots are open.

Setout truck removes a full van if less than 2 slots are open.

D. Trucks, vans, and setout trucks

3 trucks
6 vans
1 setout truck
3 slots for vans at the chip chute

E. Daily production quotas

Fell and bunch	25,000.0
	cu. ft. daily
Skid	16,000.0
	cu. ft. daily
Chip	13 vans daily
Truck	13 vans daily

Feller-Buncher Production and Cost Summary

A.	3	Days worked by feller-buncher(s).
B.	3	Number of feller-bunchers.
C.	\$15.00	Feller-buncher cost per hour including labor.
D.	1611	Total accumulator cycles completed--all machines.
E.	48.10	Average volume per cycle, cu. ft.
F.	2.52	Average number of trees per cycle.
G.	711	Total bunches completed--all machines.
H.	108.99	Average volume per bunch, cu. ft.
I.	5.70	Average number of trees per bunch.
J.	2.26	Average number of cycles per bunch.
K.	4055	Total trees felled--all machines.
L.	77493.21	Total volume felled cu. ft.--all machines.
M.	20.28	Total acres felled--all machines.
N.	316,069	Total distance traveled ft.--all machines.
O.	17.90	Average number of accumulator cycles per machine hour.
P.	7.90	Average number of bunches completed per machine hour.
Q.	45.06	Average number of trees felled per machine hour.
R.	861.04	Average volume felled per machine hour--cu. ft.
S.	.23	Average acreage felled per machine hour.
T.	3511.88	Average distance traveled per machine hour--ft.
U.	.33	Feller-buncher cost per tree.
V.	1.74	Feller-buncher cost per 100 cu. ft.
W.	65.21	Feller-buncher cost per acre.
X.	3	Feller-bunchers still working.
Y.	9.72	Acres remaining to be felled.

Skidding Production and Cost Summary

A.	2	Days worked by skidder(s).
B.	3	Number of skidder(s).
C.	\$15.00	Skidder cost per hour, including labor.
D.	327.00	Bunches skidded--all machines.
E.	1721	Trees skidded--all machines.
F.	32866.77	Volume skidded, cu. ft.--all machines.
G.	8.61	Acres skidded--all machines.
H.	372126	Distance skidded, ft.--all machines.

I.	5.45	Bunches skidded per machine hour.
J.	28.68	Trees skidded per machine hour.
K.	547.78	Volume skidded per machine hour--cu. ft.
L.	.14	Acres skidded per machine hour.
M.	6202.10	Distance skidded per machine hour.
N.	569.00	Average one-way skid distance per trip--feet.
O.	11.01	Average round trip time in minutes--all activities.
P.	8.54	Productive time--landing to woods and return.
Q.	1.73	Productive time--landing activity.
R.	.50	Nonproductive time--waiting in the woods for a bunch.
S.	.25	Nonproductive time--waiting to drop the bunch at the chipper.

Interactions with the chipper; number of trips that:

T.	15	Skidders caught up to a feller-buncher.
Of these "catch-up" trips, the number of trips that the skidders:		
U.	10	Immediately took the bunch as it was.
V.	3	Waited for the bunch to get bigger.
W.	2	Attempted to switch to another feller-buncher.

Interactions with the chipper; number of trips that were:

X.	292	Skidded direct to the chipper.
Y.	35	Skidded direct to the stockpile.
Z.	17	Number of stockpile-chipper shuttle trips.
AA.	\$.53	Skidding cost per tree.
BB.	\$2.75	Skidding cost per 100 cu. ft.
CC.	\$104.53	Skidding cost per acre.
DD.	21.39	Acres remaining to be skidded.

Chipper-Loader Production and Cost Summary

A.	1	Days worked by chipper-loader.
B.	\$50.00	Chipper-loader cost per hour, including labor.

C.	252	Loads chipped.
D.	2.53	Average number of stems per load.
E.	48.27	Average volume per load, cu.ft.
F.	637	Trees chipped.
G.	12164.37	Volume chipped, cu. ft.
H.	13	Vans filled.
I.	19.38	Average number of loads per van.
J.	935.72	Average volume per van, cu. ft. solid wood.
K.	25.20	Loads chipped per machine hour.
L.	63.70	Trees chipped per machine hour.
M.	1216.44	Volume chipped per machine hour, cu. ft.
N.	1.30	Vans filled per machine hour.
O.	46.15	Average chipping time per van filled--all activities--minutes.
P.	29.13	Productive time per van--minutes.
Q.	17.02	Nonproductive time per van--minutes.
R.	6.60	Loader waiting for wood from skidders--minutes.
S.	10.42	Chipper waiting for vans to fill--minutes.
T.	\$.78	Chipper-loader cost per tree.
U.	\$4.11	Chipper-loader cost per 100 cu.ft.
V.	\$38.46	Chipper-loader cost per van filled.

Truck, Van, and Setout Truck Production and Cost Summary

A.	3	Number of trucks.
B.	\$25.00	Truck cost per hour, including labor, each.
C.	6	Number of vans.
D.	\$15.00	Van cost per day, each.
E.	1	Number of setout trucks.
F.	\$15.00	Setout truck cost per day, each.
G.	13	Vans hauled to mill--total.
H.	13	Average number of vans hauled per day.
I.	12164.37	Volume hauled to mill--total--cu. ft.
J.	138.46	Average round trip trucking time--all activities--minutes.
K.	97.20	Productive time--minutes.
L.	41.26	Nonproductive time--minutes. Waiting:
M.	12.19	For a slot to become available.

N.	4.47	In a slot for the van to be filled.
O.	0.00	At the storage area for the setout truck to bring a full van.
P.	12.57	To be weighed at the mill.
Q.	12.03	To be dumped at the mill.
R.	5.00	Average number of empty vans setout truck moved to chipper per day.
S.	3.00	Average number of full vans setout truck moved to storage area each day.
T.	\$57.69	Trucking cost per trip.
U.	\$6.92	Van cost per trip.
V.	\$1.15	Setout truck cost per trip.
W.	\$6.17	Truck cost per 100 cu. ft.
X.	\$0.74	Van cost per 100 cu. ft.
Y.	\$.12	Setout truck cost per 100 cu. ft.

Overall Production and Cost Summary

Number of machines.

A.	3	Feller-bunchers.
B.	3	Skidders.
C.	3	Trucks.
D.	6	Vans.
E.	1	Setout trucks.

Days worked by each segment:

F.	3	Feller-bunchers.
G.	2	Skidders.
H.	1	Chipper and trucks.

Volume produced by each segment to date, cu. ft.

I.	77493.21	Felled and bunched.
J.	32866.77	Skidded.
K.	12164.37	Chipped.
L.	12164.37	Hauled to mill.

Projected costs per 100 cu. ft. delivered to the mill and attributed to each segment.

M.	\$1.74	Feller-bunchers.
N.	\$2.75	Skidders.
O.	\$4.11	Chipper-loader.
P.	\$6.17	Trucks.
Q.	\$0.74	Vans.
R.	\$.12	Setout trucks.
S.	\$15.63	Total cost per 100 cu. ft.
T.	\$28.25	Chip price per 100 cu. ft. delivered to mill.
U.	\$12.62	Projected net revenue per 100 cu. ft. delivered to mill.

Bradley, Dennis P., Frank E. Biltonen, and Sharon A. Winsauer.
1976. A computer simulation of full-tree field chipping
and trucking. USDA For. Serv. Res. Pap. NC-129, 14 p.,
illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Describes a computerized model of a full-tree field
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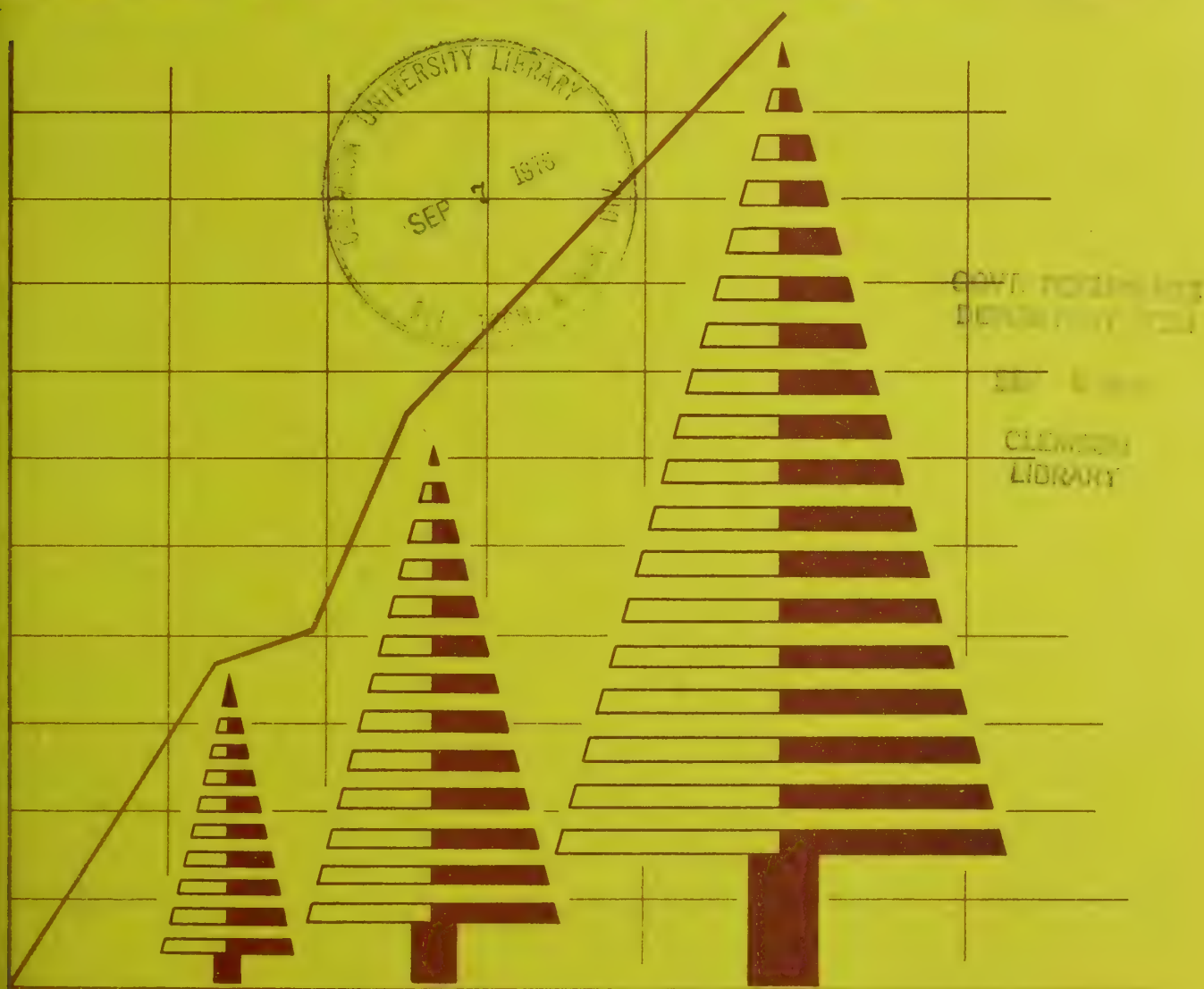
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Estimating red pine site index in northern MINNESOTA

DAVID H. ALBAN



CONTENTS

APPLICATION	1
Key to Methods for Estimating Red Pine Site Index in Minnesota	1
Estimating Red Pine Site Index from Site Index Curves	2
Estimating Red Pine Site Index by the Growth Intercept Method	2
Estimating Red Pine Site Index from Soil Properties	3
Estimating Red Pine Site Index from the Growth of Other Species	4
DOCUMENTATION	6
Red Pine Growth	6
Soil Properties	6
Field Sampling of Natural Red Pine Stands	6
Plantations	7
Sampling and Analysis of Aspen Stands	7
Laboratory Soil Analysis	7
Conversion of Percent by Volume Coarse Material to a Weight Percentage	8
Statistical Analysis	8
Stratification of Stands on Basis of Till	8
Relation of Soil Properties to Red Pine Site Index	8
Soil Mapping Units	10
Associated Species	11
Literature Cited	11

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WHAT DO YOU THINK?

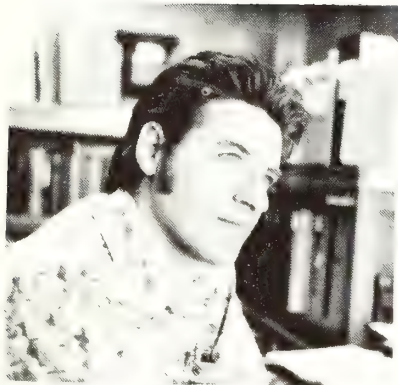
Realizing that the needs and interests of our two major "clients"--the scientist and the practitioner--are different, we have been concerned whether our publications have been in a form and style equally useful to both. So we have decided to try a new format for some of our Research Papers, one that might serve this dual purpose better.

The Paper is divided into two separate parts: Application and Documentation. The Application section is specifically intended for the man on the ground or in the mill who has a particular job to do or problem to solve. This section describes briefly the situation and the problem, and then goes immediately to the solution, emphasizing the how-to-do-it aspect. It is a complete story in itself; the busy manager need read no further.

The Documentation section describes the details of the research process. It is for the reader interested in laboratory and field procedures, tabulations, statistical analysis, and philosophical discussion. This section, too, is self-contained.

Our purpose is to separate the practical aspects of our research results from the strictly academic ones yet still make both available to all readers. If the practitioner wants to find out how we arrived at our recommendations, the details are in the Documentation section for him to examine. If the scientist has a practical bent, he can turn to the Application section and see the results in action.

It is for you to decide whether we have created a well-matched team or a two-headed monster. We would like to have your opinion.



THE AUTHOR

David H. Alban is a Research Soil Scientist stationed at Grand Rapids, Minnesota. He received a B.S. degree in forest management from the University of Washington in 1962 and a Ph.D. in soils from Washington State University in 1967. His research has been on evaluation of forest site quality and the biomass-nutrient relations of northern conifers and aspen.

ESTIMATING RED PINE SITE INDEX IN NORTHERN MINNESOTA

David H. Alban

Red pine (*Pinus resinosa* Ait.) is a commonly planted tree species in the northern Lake States. For best success, planting sites should be selected on the basis of their suitability for the species.

Several methods of estimating red pine site index (height of dominant and codominant trees at age 50) are available

(Alban 1972, Carmean and Vasilevsky 1971, Gevorkiantz 1957a). This paper incorporates this earlier work and presents new information that allows site index estimates to be made from soil properties and from the growth rate of quaking aspen (*Populus tremuloides* Michx.). Methods of field sampling and laboratory analysis for this new information are detailed in the Documentation section.

APPLICATION

Most methods recommended here are applicable throughout the commercial range of red pine in northern Minnesota. However, most red pine stands occur on well drained sandy soils. Our sampling has been most intensive on these sites,

and it is on similar sites where the proposed methods of estimating red pine site index are most reliable. The best method to use depends on the age of the red pine on the site in question and whether any red pine is indeed present.

KEY TO METHODS FOR ESTIMATING RED PINE SITE INDEX IN MINNESOTA

	<i>Recommended method</i>	<i>Table or figure</i>
I. Soils moderately well to excessively drained ¹		
A. Sandy to loam soils		
a. Red pine present		
1. Age 25 yrs+	Site index curves	Figure 1
2. Age 15 to 25 yrs	Growth intercept	--
3. Age 0 to 15 yrs	Soil properties	Tables 1 and 2
b. No trees present	Soil properties	Tables 1 and 2
c. Other species present	Inter-species relations or Soil properties	Figure 2 Tables 1 and 2
B. Finer textured soils		
a. Red pine present		
1. Age 25 yrs+	Site index curves	Figure 1
2. Younger trees	No method available	--
b. No trees present	No method available	--
c. Other species present	No method available	--
II. Poorly drained soils	Red pine not recommended	--

¹Soil drainage class are defined in Soil Survey Staff (1951).

ESTIMATING RED PINE SITE INDEX FROM SITE INDEX CURVES

The best indicator of site quality for a tree species is its extended growth performance on the site in question. Indirect measures of site quality such as climate, soil properties, associated tree species, or understory plants must be related to tree growth and cannot be expected to be as precise as measuring the trees themselves. Site index trees should be dominants, free of disease, insect, or fire damage, and should be part of an even-aged, well stocked stand that has not suffered severe environmental disturbances such as fire, erosion, or overgrazing.

Measure tree height to the nearest foot, and estimate total age by adding 8 years to the ring count at breast height (Alban 1972). Ten to 20 trees should be measured throughout the stand, the number depending on the precision desired and the stand variation. Then refer to site index curves (Gevorkiantz 1957a) (fig. 1). Alternatively, height and age can be used

to predict site index by using an equation that has been fitted to the site index curves (Lundgren and Dolid 1970):

$$\text{Site index} = \frac{\text{Height}}{[1.956 - 2.1757 e^{(-0.01644)(\text{age})}]}$$

where: e = base of the natural logarithms (2.178).

ESTIMATING RED PINE SITE INDEX BY THE GROWTH INTERCEPT METHOD

For stands younger than 25 years, site index can be estimated from internode lengths (growth intercept method) as proposed by Day *et al.* (1960) and modified by Alban (1972).

To use growth intercept, measure the total length of 5 internodes on 10 to 20 dominant trees, beginning at the first limb above 8 feet. Estimate site index by the following equation:

$$\text{Site index} = 32.5 + 3.43 \text{ growth intercept}$$

or table:

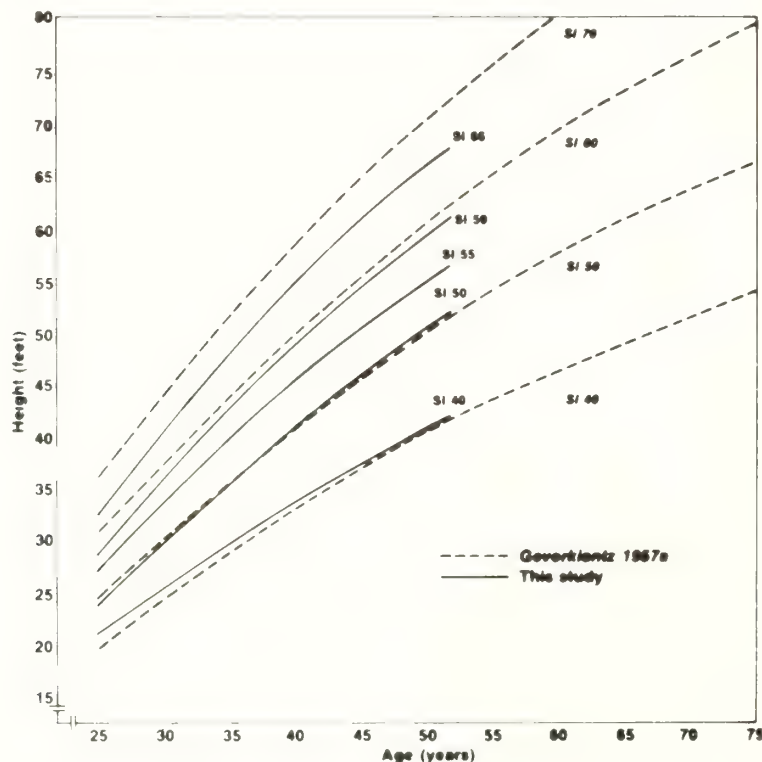


Figure 1.--Red pine site index curves and height growth curves. Six stands averaged SI 40, 12 stands SI 50, 14 stands SI 55, 30 stands SI 59, and 10 stands SI 66.

Length of five internodes above Site index
8 feet (growth intercept) (feet)
(feet)

4	46
5	50
6	53
7	57
8	60
9	63
10	67
11	70
12	74

ESTIMATING RED PINE SITE INDEX FROM SOIL PROPERTIES

Where no suitable red pine trees are present, soil properties can be used to estimate site quality. To estimate site index from soil properties the till material from which the soil developed must be identified as either Keewatin till (north-western source) or Rainy till (northeastern source) (Arneman and Wright 1959). In nearly all red pine stands sampled in St. Louis or Lake counties the soils were derived from Rainy till whereas soils to the west were derived from Keewatin till.

Rainy Till Area

Rainy till soils commonly contain much coarse material (greater than 2 mm diameter); bedrock is generally shallow. The percent (by oven-dry weight) of coarse material in the top 40 inches of soil and the total thickness of the A and B horizons are closely related to site index by the following equation:

$$\text{Site index} = 42.78 - 0.0864(X_1) + 6.504 \ln(X_2)$$

where: X_1 = percent of coarse material by weight in the 0 to 40 inch layer, and X_2 = thickness of A and B horizons (inches).

This equation accounts for 86 percent of the site index variation ($R^2 = 0.86$), and has a standard error of estimate of 3.0 feet.

As an alternative, use table 1.

Where bedrock is less than 40 inches from the surface, its weight (which must be added to the weight of coarse materials) can be calculated from its density, which is estimated at 2.65 g/cm³ (165 lb/ft³) (Wilde 1958). If the coarse material fraction is known by volume, it can be converted to weight (fig. 2).

Keewatin Till Area

Keewatin till soils tend to have thicker solums and to be sandier than Rainy till soils, but have far less coarse material. Coarse soil material and depth of the A+B horizons are related to site index in the Keewatin area as in the Rainy area. In addition to these two properties, the presence or absence of finer textured bands is closely related to site index. Forty out of the 52 stands sampled had sandy soils of glacial outwash or lacustrine origin, and about half of these had strong texture bands below the solum. These bands commonly occur as irregular layers or lenses ranging in texture from sandy loam to clay but always finer than the adjacent layer.

On the basis of texture bands or underlying finer materials, the Keewatin area soils are divided into two categories.

Table 1.--Red pine site index in Rainy till area based on soil coarse fraction and thickness of A and B horizons¹

Coarse fraction 0-40 inch depth (percent by weight)	Thickness of A and B horizons (inches)						
	2	5	10	15	20	25	30
0			58	60	62	64	65
10			57	60	61	63	64
20			56	59	61	62	63
30			55	58	60	61	62
40			54	56	59	60	61
50			53	56	58	59	61
60		48	53	55	57	59	60
70	41	47	52	54	56	58	
80	40	46	51	53			
90	40	46	50				
95	39	45					

¹ Based on: Site index = 42.78 - 0.0864 (coarse material percent) + 6.504 ln (thickness of A + B horizons).

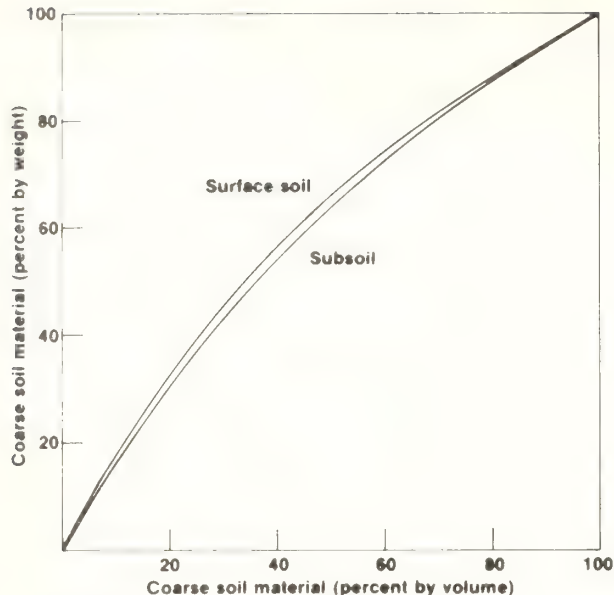


Figure 2.--Relation between soil coarse fractions expressed on a volume and weight basis.

Group I soils have textural bands that total more than 6 inches in thickness (to a depth of 9 feet), those developed in sandy soils underlain by finer materials, or those developed within finer materials. The Group 0 soils are sandy and lack either strong textural banding or underlying finer materials.

Estimate red pine site index from soil properties on Keewatin till areas by using the following equation:

$$\text{Site index} = 49.03 - 0.317(X_1) + 0.313(X_2) + 4.98(X_3)$$

where: X_1 = percent of coarse material (> 2 mm) by weight in 0 to 10 inch layer,

Table 2.--Red pine site index in Keewatin till area based on soil coarse fraction and thickness of A and B horizons¹

Coarse fraction 0-10 inch depth (percent by weight)	Group I ²				Group 0			
	Thickness of A + B (inches)				Thickness of A + B (inches)			
	10	20	30	40	10	20	30	40
0	57	60	63	66	52	55	58	62
5	56	59	62	65	51	54	57	60
10	54	57	60	63	49	52	55	58
20	51	54	57	60	46	49	52	55
30	48	51	54	57	43	46	49	52
40	44	48	51	54	40	43	46	49

¹ Based on: site index = 49.03 - 0.317 (coarse material percent) + 0.313 (thickness of A + B horizons) + 4.98 (presence of finer textured layers).

² Group I plots are those with fine textured soil layers or bands as explained in the text; group 0 plots lack this feature.

X_2 = thickness of A and B horizons (inches), and X_3 = 1 for Group I soils and 0 for Group 0 soils.

This equation accounts for 57 percent of the variation ($R^2 = 0.57$) and has a standard error of estimate of 4.4 feet.

As an alternative, use table 2.

ESTIMATING RED PINE SITE INDEX FROM THE GROWTH OF OTHER SPECIES

The growth of red pine can be predicted from the growth of several other species growing on the site. In northern Minnesota, data from soil and forest survey plots can be used to estimate red pine site index from the site index of jack pine (*Pinus banksiana* Lamb.) (66 plots), white pine (*Pinus strobus* L.) (58 plots), and white spruce (*Picea glauca* Moench.) (15 plots) (Carmean and Vasilevsky 1971). The site index prediction equations follow:

$$\text{Site index}_{rp} = 1.0(\text{Site index}_{jp}) - 2.81 \quad r^2 = 0.40$$

$$\text{Site index}_{rp} = 0.95(\text{Site index}_{wp}) + 3.57 \quad r^2 = 0.47$$

$$\text{Site index}_{rp} = 0.70(\text{Site index}_{ws}) + 18.90 \quad r^2 = 0.65$$

From a similar study on 26 plots in Minnesota (Documentation Section) red pine site index can be estimated from the site index of quaking aspen:

$$\text{Site index}_{rp} = 0.44(\text{Site index}_{qa}) + 27.88 \quad r^2 = 0.53$$

A graph of these equations facilitates species comparisons (fig. 3). Site index for jack pine, white pine, white spruce, and aspen can be determined from total height and age by using published site index curves (Gevorkiantz 1956a, 1956b, 1957b, 1957c).

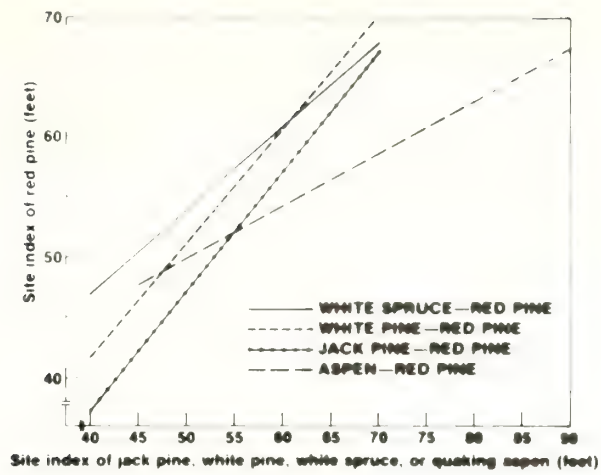


Figure 3.--Estimates red pine site index from the site index of jack pine, white pine, white spruce, or aspen.

RED PINE GROWTH

Red pine height growth patterns are remarkably similar throughout the species' range. Spurr (1955), for example, found a single set of site index curves to be adequate for red pine stands (including plantations) from Minnesota to New England and into Canada. His curves are similar to those used in Minnesota (fig. 1). Similarly, the height-growth pattern to age 25 of red pine in Minnesota (plantations and natural stands) was found to match that in the northeastern United States on similar sites (Alban 1972).

In Minnesota the best natural red pine stands have a site index of about 70, and the best plantations (by extrapolation for about 15 years) a site index of 75 to 80. Others have found an upper limit to red pine site index of about 70 (Richards *et al.* 1962, Spurr 1955, Wilde *et al.* 1965). A few reports (Ek 1971) claim red pine site index values as high as 112 but these estimates of high site index were made in young plantations and later measurements usually show the apparent site index to be decreasing with age.

Volume growth in young trees may be different in plantations than in natural stands because of more uniform stocking in plantations. But, as the stands close and fully occupy the site (at perhaps 20 to 30 years), volume growth rates would probably be similar on similar sites.

The height growth of red pine stands at least 50 years old is the most reliable indicator of site index available. Stand height and age are measured directly and site index read from site index curves (Gevorkiantz 1957a). The accuracy of these curves is substantiated by our stem analysis of 231 trees in 71 Minnesota natural stands (fig. 1).

When red pine trees 15 to 25 years old occupy a site, the site index can be estimated by the growth intercept method (Alban 1972). This method is easier to use than standard site index curves and eliminates the need to measure total height and age, each of which can be a source of error. However, the growth of red pine stands younger than about 10 years is not a reliable indicator of site index (Alban 1972).

SOIL PROPERTIES

Where red pine trees are absent or very young, soil properties are useful indicators of site quality. Emphasized here are soil properties that can be measured in the field and in the laboratory with simple techniques such as weighing and sieving.

FIELD SAMPLING OF NATURAL RED PINE STANDS

A 0.1-acre plot was established in each of 71 natural red pine stands in northern Minnesota. Seventy-nine percent of the plots sampled occurred in Lake, St. Louis, Itasca, Cass, or Beltrami counties, which contain 74 percent of the total red pine acreage in Minnesota (Stone 1966). Most stands occurred on gently rolling, well drained upland soils of sand to sandy loam texture developed from glacial outwash or lacustrine sands. The major criteria of stand selection included: (1) uniformity of topography and surface soil texture, (2) even-aged stands more than 40 years old, and (3) more than 75 ft²/acre basal area, of which at least 75 percent was red pine. None of the stands has a history of crop or pasture use, and none shows evidence of severe fires, early suppression, or insect or disease damage. A summary of soil and stand properties for these stands is shown in table 3.

On each 0.1-acre plot, diameter outside bark was measured at breast height for each tree larger than 1 inch in diameter at breast height. Three to seven randomly selected dominant trees were felled, total height measured, and the bole sectioned as follows: 1-foot sections from the 6-inch stump to 6.5 feet; 2-foot sections from 6.5 to 20.5 feet; and 3-foot sections from 20.5 feet to the top of the tree. On each section the diameter and bark thickness were measured and the annual rings counted. Total age was estimated by adding 2 years to the ring count at the 6-inch stump. From the ring counts on each section a single average height-growth curve was constructed for each plot. From this curve total height at age 50 (site index) as well as heights at various other ages and the number of years required to reach breast height were determined.

Table 3.--Soil, stand, and climatic factors for the study area¹

Property	Northeastern Minnesota		North-central Minnesota	
	Rainy till plots		Keewatin till plots	
	Mean	Range	Mean	Range
Site index (ft)	56	39-69	57	37-68
Basal area (ft ² /acre)	172	104-224	171	110-235
Stand age (yr)	67	48-86	66	44-94
Average annual precipitation (in.)	--	26-29	--	22-26
Average summer temperature (°F)	--	61-64	--	64-66
Forest floor weight (lb./acre/1,000)	32	13-59	24	7-40
Surface soil (0-10 inches)				
Silt + clay (percent)	32	11-49	20	3-85
Bulk density (g/cm ³)	1.27	1.08-1.33	1.33	1.21-1.43
pH	5.3	4.5-5.8	5.6	5.2-6.0
N (Kjeldahl) p/m	749	254-2,100	394	260-639
P (0.01N HCl) p/m	12	0.2-30	28	10-53
Ca (Exch.) p/m	349	190-850	330	160-750
K (Exch.) p/m	75	39-156	52	31-79
CEC meq/100 g	3.7	2.2-6.4	2.7	1.8-4.0
Available H ₂ O storage cap percent	15	6-22	9	4-23
Coarse material (0-40 inches) percent	39	0-97	7	0-43

¹ The climatic data are from Baker *et al.* (1967), and Baker and Strub (1965); all other data measured on samples collected from 71 natural red pine stands in Minnesota.

The forest floor horizons (L, F, and H) were collected from five locations on each plot with a 1-square foot sampling frame. Two soil pits 6 feet deep were dug on each plot (if not prevented by bedrock or a water table) and borings 3 to 4 feet deeper were made; soils were described and soil samples collected from each of the major horizons. In addition two smaller pits were dug 3 feet deep, and soil from each of the four pits was combined to form two composite soil samples per plot, one from the 0 to 10-inch depth and another from the 10 to 40-inch depth. All rock material greater than 1 inch in diameter was weighed in the field. Bulk density was determined in the deeper soil pits using a core sampler for the sandy soils, and excavation for the finer textured soils.

PLANTATIONS

Twenty additional plots were established in red pine plantations averaging 30 years of age to compare the pattern and early growth rates of red pine from plantations and natural stands. Stem analysis was performed on these trees as for the older trees in natural stands. The soils were examined from auger borings or nearby road cuts, but no detailed soil sampling or analysis was done.

SAMPLING AND ANALYSIS OF ASPEN STANDS

Twenty-six plots were established throughout northern Minnesota in aspen

stands in which height growth and site index had previously been determined by stem analysis (Schlaegel 1974). All plots were on sandy to loam soils. The stands ranged in age from 19 to 81 years (mean 47 years) and in site index from 47 to 90 (mean 72). Eighteen of the plots occurred on Keewatin derived soils and eight were on Rainy till.

Four pits were dug on each plot, from which coarse material content, depth of A and B horizon, and presence of fine textured layers were determined. These values were applied to the appropriate equations (p.344) to estimate red pine site index. The statistical relation between red pine and aspen site index values was then determined following Carmean and Vasilevsky (1971) who compared site index of red pine with jack pine, white pine, and white spruce.

LABORATORY SOIL ANALYSIS

Mineral soil samples were air-dried, hard structural peds crushed, and the soil sieved on a 2 mm screen. That portion passing through the 2 mm screen was used for subsequent analysis and adjustments made in results for moisture in the air-dry soil and for coarse material content.

Soil reaction was measured in a 1:1 soil and water mixture. Nitrogen was measured by the macro Kjeldahl method. Soil phosphorous was extracted with 0.01N

HCl and determined colorimetrically. "Exchangeable" Ca, Mg, and K were extracted with 1N NH_4OA and determined by atomic absorption. "Exchangeable" H and Al were extracted with 1N KCl and determined by titration with NaOH and HCl (Yuan 1959). Cation exchange capacity was taken to be the sum of all determined cations. Particle-size distribution was determined by hydrometer, and available water-storage capacity was determined as the difference between water held at 0.1 atm and 15 atm of tension in pressure apparatus.

Forest floor samples were air-dried and ground in a Wiley mill to pass a 20 mesh screen. Nitrogen was determined by the macro Kjeldahl method. Subsamples were ashed at 525°C for 2 hours and taken up in dilute HCl. Total Ca, Mg, K, and P were determined in the HCl extract by the same methods as used for the mineral soils. Reaction was measured in a 1:4 sample and water mixture.

CONVERSION OF PERCENT BY VOLUME COARSE MATERIAL TO A WEIGHT PERCENTAGE

The most accurate way to measure coarse materials is by weight because it is difficult to estimate the volume of the smaller gravels. But because coarse materials are often estimated on a volume basis, a graph was constructed to convert coarse material percentage from a volume to weight basis (fig. 2). In constructing the graph it was assumed that density of the coarse materials is 2.65 g/cm^3 and that the soil bulk density is 1.30 g/cm^3 for the surface soil and 1.45 g/cm^3 for the subsoil. The soil bulk density values are averages found in the present study for soils supporting red pine in northern Minnesota.

STATISTICAL ANALYSIS

Individual soil properties were graphed and regressed against red pine site index to determine those properties most closely related to site index. Properties examined included stand age and basal area; depth to or thickness of various soil horizons, textural bands, water table, carbonates, gravel layers; coarse material content, particle size distribution, and water-holding capacity; pH, cation-exchange capacity, and nutrients (N, P, K, Ca, Mg) in forest floor and mineral soil. For the present report only the field observable

and easily determined laboratory properties were combined into multiple regression equations. The equations were constructed beginning with the soil property having the best correlation with site index and adding other properties one at a time. Addition of new variables was terminated when the last failed to increase R^2 by 0.03 or if its coefficient was not different from zero at the 10 percent confidence level.

STRATIFICATION OF STANDS ON BASIS OF TILL

The Keewatin till is distinguished by the presence of limestone, the frequent presence of shale, a low rock content, buff color, and generally a loamy or silty texture. The rainy tills are sandy, brown to reddish brown in color, and have a high rock content. A third Minnesota till, the Superior, is found in the area to the southwest of the Lake Superior basin and at one time supported considerable red pine. But, because of extensive logging, fire, and farming, too few suitable stands of red pine were found on this till material to be included in this report. More detail about the characteristics of the tills can be found in the report of Arneman and Wright (1959).

Red pine occurs on both the tills themselves and on the outwash and lacustrine deposits derived from the till. Most red pine plots in St. Louis County and eastward were on soils formed from Rainy till, whereas soils to the west of St. Louis County were derived primarily from the Keewatin till. Usually the geographical location of a site will be an excellent indicator of the kind of till from which the soil was developed. Where in doubt, particularly along the St. Louis-Itasca County boundary, the soils must be examined to determine the till source.

RELATION OF SOIL PROPERTIES TO RED PINE SITE INDEX

In general, red pine stands occur on well drained sandy soils and commonly in association with jack pine or white pine. The presence of fine textured layers in or below the solum of sandy soils or the presence of fine textured material underlying sandy soils results in better red pine growth than on sandy soils without these features (Alban 1974a, Hannah and Zahner 1970, Van Eck and Whiteside 1963,

White and Wood 1958). On these soils red pine growth is better than its hardwood competitors, such as aspen and sugar maple, which do poorly on these sites. The hardwoods reach their best growth on the finer textured soils (Post 1968, Stoeckeler 1960) but here red pine growth may be only slightly better than on many sandy soils (Alban 1974a, Wilde *et al.* 1965). Poorly drained soils are not suited to red pine (Dreisinger *et al.* 1956, Stone *et al.* 1954, Wilde and Voigt 1967).

In both the Rainy and Keewatin till areas, the content of coarse material and the thickness of the A and B horizons are important in estimating red pine site index. Hence the determination of the depth to the bottom of the B horizon becomes very important. B horizons in both the Rainy and Keewatin till soils are characterized by various accumulations of clay, organic matter, and sesquioxides. The B horizons characteristically have darker brown or more reddish-brown color, and slightly more clay than surrounding horizons. Bedrock or coarse sand or gravel is sometimes found beneath the B horizons; more commonly soil material similar to the B horizon but little affected by soil-forming processes occurs below this horizon.

Both horizon depth and coarse material content can vary greatly even within small areas. To obtain reasonable estimates of these soil properties requires a minimum of four soil pits on even small (perhaps up to 40 acres) management tracts, the number needed depending on the precision desired, and on the variability of the soils, which would become apparent after examining the first few pits. Soil variability for certain properties of northern Minnesota soils and methods for estimating adequate sample size have been reported (Alban 1974b).

The coarse material in the Rainy till soils is crucial because the higher the coarse material content the lower storage capacity for nutrients and water. Hence, adding terms for soil nutrients or water-holding capacity to the equation improves its accuracy only slightly. On the other hand, for stands on Keewatin till, more precise equations were developed when using soil nutrients as factors (Alban 1974a). For example, an equation with terms for surface soil N, P, and K and

for Groups I and O resulted in an R^2 value of 0.79. However, these properties are easily altered by vegetation changes or by man's activities, so the use of more stable properties is preferred because they are more reliable indicators of long-term site productivity.

The presence or absence of textural banding in Keewatin till soils greatly affect red pine site index. About 40 percent of the red pine stands sampled on soils of Keewatin till had 1 to 10 bands up to 10 inches thick each, within the top 9 feet of soil. All bands have abrupt boundaries with the surrounding sandy material, and many roots are concentrated at the top of and within the thicker bands. Similar bands have been described and analyzed in detail for Michigan soils (Wurman *et al.* 1959). No significant relations were found between site index and depth to the band or the texture of the band.

Surface soil texture (or silt + clay content) was not significantly related to site index, and even large differences in texture had little or no effect on site index. For example, in Keewatin stands the 6 plots occurring on glacial till (silt + clay content of surface soil greater than 30 percent) averaged 61 site index. This is higher than the average for all Keewatin plots (57) but almost identical to the average for the Group I (banded) plots. Thus, the moderately heavy textured soils (heavy sandy loam to silt loam) are not better red pine sites than the better sandy soils. This agrees with similar findings in Wisconsin (Wilde *et al.* 1965). In New York, heavier textured but well drained soils had higher red pine site index than sandy soils (DeMent and Stone 1968), but the sandy soils in that area are commonly abandoned farms that are deficient in K and Mg. Neither of these elements is likely to be found deficient in northern Minnesota sandy soils (Alban 1974a).

Because of the importance of coarse materials, particularly in the Rainy till area, the modifiers of soil textural class, such as gravelly or very gravelly, do indicate a reduced site index. For example, of the poorest 9 sites (mean site index = 50) 7 had gravelly surface soil, whereas of the 10 best sites (mean site index = 60) only 1 had a gravelly surface soil.

Slope and aspect, which in other regions strongly affect site quality (Ralston 1964), are of little importance for red pine in Minnesota, primarily because of the subdued character of the landscape. In the Rainy till area, for example, only 4 of the 19 plots sampled had slopes greater than 5 percent (maximum 15 percent) and, although this is clearly a limited sample, none of these 4 was among the best or the poorest of the red pine sites. In both till areas, plots located on narrow ridgetops or at the tops of small knolls were of poor site quality, but such areas occupy only a small percentage of any stand examined. Further, these topographic positions nearly always have more coarse material and thinner solums than soils of the surrounding area. And these factors serve adequately to estimate site index.

None of the Rainy till stands had a water table within the sampling depth. Ten of the 52 Keewatin stands had water tables ranging from 3 to 9 feet below the soil surface, but neither the presence of a water table nor the depth to it was related to site index. The average site index for the 10 plots with a water table was 55, which is close to the average value for all Keewatin plots of 57. The seven best Keewatin sites had no water table within 9 feet, indicating that a shallow water table is not necessary for good growth.

SOIL MAPPING UNITS

Ideally, we would like site productivity to be an easily mappable feature of the landscape. And to this end many attempts have been made to relate soil mapping units to tree growth with various degrees of success. Most soil series are too heterogenous to be useful for predicting forest productivity (Jones 1969). Subdividing soil series into phases based on properties shown to be important to tree growth could reduce variation within series (Carmean 1961). But lack of detailed knowledge of the factors limiting growth, and of detailed knowledge of the range in these properties within soil mapping units have limited the application of this refinement.

Soil series and phases in relation to red pine plantation growth have been studied in Michigan (Van Eck and Whiteside 1963), New York (DeMent and Stone 1968), and

Wisconsin (Wilde *et al.* 1965). Each of these studies showed a few soil units that related to poor red pine site quality because of shallowness to bedrock, extreme droughtiness, or restricted drainage. But, except for the very poor sites, soil mapping units in these studies were of limited help in distinguishing red pine productivity units.

In Minnesota the Soil Conservation Service, in cooperation with the North Central Forest Experiment Station, has evaluated tree growth in relation to soil mapping units as part of its interpretive program for soil surveys. The results for red pine have not been encouraging. For example, in north-central Minnesota at least four sample plots were found on nine soil mapping units (Hiwood, Kinghurst, Marquette, Menahga-banded, Menahga-non-banded, Rockwood, Swatara, Taylor, and Todd) (USDA, SCS, and NCFES, 1968). There were no significant differences in red pine site index among these nine units. Similarly, when soils were grouped into broad "Woodland Suitability Groups," no significant differences in red pine site index were found among the five groups containing red pine.

In the present study most plots were in areas for which there are no detailed soil maps so as mapping progresses new units will undoubtedly be needed and older ones will be redefined. Hence, assigning many plots to defined soil mapping units is tenuous at best. However, in the Keewatin till area, four reasonably secure mapping units were represented by enough plots to present a useful sample of productivity (table 4). Clearly, there is little if any difference between the sands (Menahga) and the fine sands (Shawano). There is more difference between banded and nonbanded soils, as would be expected, but the differences are not significant. The average range of site index on these four soils is 14, which is about half the total site index spread for red pine and represents large differences in volume growth (Buckman 1962).

In view of all this, we must conclude that soil mapping units as presently constituted are of little help in evaluating red pine site index for specific stands; they may, however, aid in evaluating other aspects of forest management such as seedling survival, erosion hazard, brush competition, frost heaving, wildlife suitability, etc.

Table 4.--Red pine site index on four soil mapping units on the Keewatin till area

Soil	Plots: Number	Site index range	Mean site index	Standard error
Menahga (sand-loamy sand)	6	51-63	55	3.1
Menahga (sand-loamy sand) banded phase	8	55-68	61	1.9
Shawano (fine sand-loamy fine sand)	6	48-61	55	3.5
Mosomo (fine sand-loamy fine sand) banded	6	51-68	60	6.4

The soil factors closely related to red pine growth, however, can be used to estimate red pine site index on a stand-by-stand basis. To expand this information to a mapping unit basis requires evaluating the range of each factor within the various soil mapping units. In general, the information on ranges necessary for this elaboration is not now available and probably will not be for some time. In specific cases, however, available data can be used in conjunction with the equation or tables presented in this report. For example, the Insula soil series has been described as being 8 to 20 inches thick over bedrock and having 15 to 35 percent (volume basis) coarse fragments (Erickson *et al.* 1971). If we assume that the A and B horizons extend to bedrock, that the soil bulk density is 1.3 g/cm³, and the rock density is 2.65 g/cm³, we can calculate the estimated range of Insula site index values for red pine as ranging from 48 to 56 by using the appropriate equation (p. 3).

ASSOCIATED SPECIES

When suitable red pine does not occupy a site and soil sampling is not feasible, the growth of other tree species can give an estimate of the site's potential for red pine (fig. 3). Because of the rare occurrence of red pine on poorly drained or heavy textured soils, the applicability of interspecies relations to these kinds of soils is unknown, so they should be used only on well drained sandy to loam soils. This is particularly important for white spruce, white pine, and aspen, which are known to grow better on the heavier soils (Wilde *et al.* 1965, Stoeckeler 1960). Red pine, as pointed out earlier, has similar growth rates over a wide range of soil textures.

Red pine site index is consistently 2.8 lower than that for jack pine (fig. 3). Within the common range of site index (40 to 70), red pine has a slightly higher value than white pine, but the difference is never more than 1.6 feet, so for practical purposes we can assume identical site index for these two species. On the poorer sites, red pine has better site index than white spruce or aspen, whereas on the better sites the reverse is true.

Similar site indexes for two species do not necessarily indicate similar biological or economic tree yield and may mask large differences in wildlife suitability or other facets of the site. For example red and jack pine will generally have nearly identical site indexes on a given site, but their volume growth may differ appreciably. Thus once site index is known for several species, the yields of these species should be determined and compared.

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For. Exp. Stn., St. Paul, Minn.

Methods are presented for estimating red pine site index from the height growth of red pine, site index of several associated species (jack pine, white pine, white spruce, or quaking aspen), and from easily measured soil properties. The restrictions and limitations of each method and their relative precision are discussed.

OXFORD: 541:174.7*Pinus resinosa*(776). KEY WORDS: *Pinus resinosa*, growth intercept, forest soils, site productivity, interspecies relations.

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an assessment of three measures of long term moisture deficiency before critical fire periods

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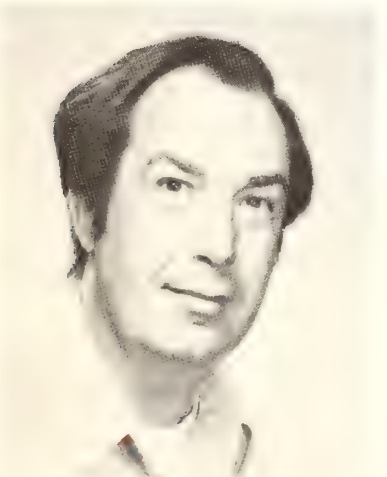
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CONTENTS

Assessment Procedures	2
Interpretation of Results	4
Conclusions	10
Literature Cited	11
Appendix I.--The Buildup Index	11
Appendix II.--The Keetch-Byram Drought Index.	12
Appendix III.--The Palmer Drought Index	12

AN ASSESSMENT OF THREE MEASURES OF LONG-TERM MOISTURE DEFICIENCY BEFORE CRITICAL FIRE PERIODS

Donald A. Haines, Von J. Johnson, and William A. Main

Accounting for long-term drying has always been a major problem in the development of forest fire danger rating systems. It is a necessary component of any fire danger rating system because it provides guidance to the fire manager during critical conditions, i.e., periods when moisture contents of soil and fuel become so low that fire control difficulties are greatly intensified. Keetch and Byram (1968) pointed out:

"The moisture content of the upper soil, as well as that of the covering layer of duff, has an important effect on the fire suppression effort in forest and wildland areas. In certain forested areas of the United States, fires in deep duff fuels are of particular concern to the fire control managers...(but)... in fire control, the critical effects of drought are not confined to deep organic soils. Dried out organic materials are frequently embedded in the shallow upper layers of mineral soils. These fuel pockets can become a deciding factor in whether or not fire lines will hold and be a further problem in mopup operations."

This does not imply that difficult forest fires cannot occur without prior, long-term moisture deficiency. For example, during early spring in the north-central and northeastern States, snowmelt is often followed by a period of dry, windy days. Greening of the low, finer vegetation has not yet occurred and conditions are ideal for fast-spreading surface fires. These types of fires may display crowning in conifer stands but rarely burn the deeper duff fuels. Consequently, low moisture amounts in the large fuels, deep duff, and soil mantle are usually not a contributing factor in this type of forest fire.

Early danger meters differed widely in their approach toward measurement of long-term drying. During the 1950's and 1960's, Buildup Indexes (BUI) were integrated into fire danger rating systems in the United States. They reflected the dryness or wetness of fuels that have a pronounced effect

on fire behavior, except the fine, flashy fuels (Nelson 1964). Fire control organizations felt that containment and mopup became progressively more difficult when BUI values increased, which gave the Index meaning operationally.

However, many believed that the BUI did not indicate extreme drying conditions. In 1968, therefore, Keetch and Byram developed a drought index, which they stressed was not a substitute for the moisture parameters used in the spread phase of the National Fire Danger Rating System. They explained:

"A drought condition is not a prerequisite for the occurrence and spread of fire in any area. The drought index does not replace the buildup index, because it represents an entirely different moisture regime in which the response to weather changes is much slower than with the buildup index. The purpose of the drought index is to provide fire control conditions in areas where such information may be useful in planning fire control operations."

Identification of the proper zone of progressive drying is a problem that also plagued other researchers, including Wayne Palmer of the National Oceanic and Atmospheric Administration. After developing a meteorological drought index (Palmer 1965), he was forced to later construct a crop moisture index (Palmer 1968). He explained:

"The Meteorological Drought Index was designed to evaluate the scope, severity, and frequency of prolonged periods of abnormally dry weather. For this purpose it works reasonably well. However, since some people have been trying to interpret it strictly as a measure of the current status of agricultural drought; i.e., as a measure of the effects of abnormally dry weather on crops, a separate procedure has been developed that responds rapidly to changes in the soil moisture situation and takes

into account only those moisture aspects which affect vegetation and field operations."

Palmer accomplished this by combining an "evapotranspiration anomaly index" and a "wetness index" (Palmer 1968). Therefore, both Palmer and Keetch-Byram independently came to the conclusion that the upper and the deeper soil layers represented such divergent moisture regimes that different bookkeeping methods were required in their description. They are not the only ones that finally arrived at a dual-entry system to identify long-term moisture deficiency because the Canadians developed a Forest Fire Weather Index that contains a Drought Code and a Duff Moisture Code (Van Wagner 1974).

ASSESSMENT PROCEDURES

In fire danger rating, is the long-term moisture deficiency best represented by:

1. large, surface fuels?
2. litter and duff layers (L, F, and H)?
3. soil profiles? or
4. living foliage?

We attempted to partially answer these questions by assessing the values for the following indexes before the 26 critical fire situations shown in figure 1:

1. The Buildup Index that was designed to represent drying in the top 2 to 3 inches of litter type fuel (see Appendix I).
2. The Keetch-Byram (K-B) Drought Index that is a moderately fast response system applicable to conditions in a layer from surface to deeper soils (see Appendix II).
3. The Palmer Drought Index that is a slow response system applicable to conditions in a layer from surface to deeper soils (see Appendix III).

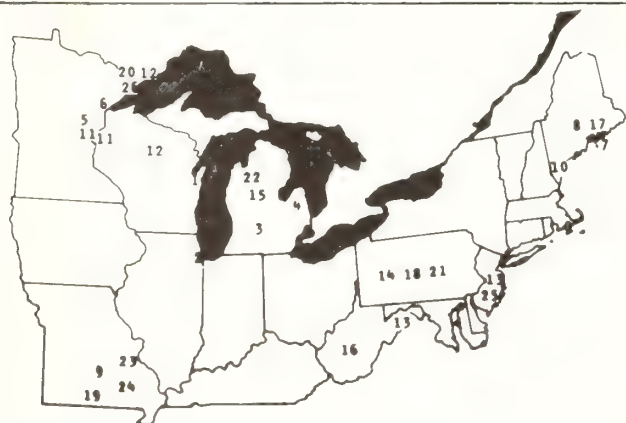


Figure 1.--General location of critical fire situations. The numbers correspond to the following:

October 8-10, 1871

- 1 Peshtigo (Wisconsin), 1,280,000 acres burned; 1,300 lives lost. Extensive areas of logging and land clearing slash interspersed with millions of acres of standing timber; mostly conifer.
- 2 Chicago (Illinois), 17,450 buildings burned; 200 lives lost.
- 3 Lower Michigan, 2.5 million acres burned; 200 lives lost. Extensive areas of logging and land clearing slash interspersed with millions of acres of standing timber; mostly conifer.

September 1-5, 1881

- 4 Thumb Fires (Michigan), 1 million acres burned; 169 lives lost. Principally large acreages of dead timber from 1871 fires, and large areas of windfalls and conifer slashings.

September 1, 1894

- 5 Hinckley (Minnesota), 160,000 forested acres burned; 418 lives lost. Fire started in large, logged-over pine areas and then moved into standing timber.

October 12, 1918

- 6 Cloquet (Minnesota), 1,280,000 acres burned; 538 lives lost. Fire started in brush, slash, and peat bogs and then moved into standing conifer timber.

October 23, 1947

- 7 Bar Harbor & York County Fires (Maine), 150 miles of fire line; 220,000 acres burned. Dense growth of spruce and other softwoods, dry stubble of cut hayfield, large volumes of slash.

May 23, 1950

- 8 Greenfield (Maine), 6,355 acres burned. High hazard area with large amounts of slash.

November 1, 1952

- 9 Missouri Fires, a 33,000 acre fire, partly on the Clark National Forest. State had

625 fires during October; Governor closed all forests. Grass, brush, and standing hardwood timber with freshly fallen leaves.

May 8-9, 1957

- 10 Sanford-Kennebunk (Maine), 13,000 acres burned, one of several large fires in the northeast and Canada. Fuel moisture 3.3 on afternoon of the 8th; severe crowning. Pine cover with old pine slash areas.

May 1, 1959

- 11 Grantsburg (Wisconsin), Moose Lake and Badoura (Minnesota), crown fires burned 26,000 combined acres at Grantsburg and Badoura. Moose Lake reported large grass fires. Natural jack pine cover with interspersed red pine plantations.

May 30, 1961

- 12 Bear Trail (Minnesota) and Boundary (Wisconsin), 600-acre crown fire on Superior National Forest; two crown fires burned 600 acres on Nicolet National Forest. Bracken fern at origin; fire burned over swamps and into standing conifer timber.

April 20-21, 1963

- 13 Paw Paw (West Virginia) and New Jersey fires, 6,626 acre fire in West Virginia; over 200,000 acres burned during spring season in New Jersey. Mostly shrub oak and pitch pine areas in New Jersey with fire carried in wind-driven oak leaves. In West Virginia cover was mixed hardwood with some Virginia pine and scrub oak.

October 14, 1963

- 14 St. Lawrence (Pennsylvania), 3 fires joined; 3,000 acres burned. Began in low vegetation along a railroad track.

April 12-17, 1964

- 15 Lower Michigan, 9 large fires burned between 306 and 3,000 acres each; crowning with high winds. Some burned in large grass areas, and also in hardwood and jack pine stands.

November 5-11, 1964

- 16 District 5 (West Virginia), 413 fires in this district during November. Five large fires burned between 1,200 and 3,370 acres.

August 4, 1965

- 17 Centerville (Maine), 12,062 acres burned with much crowning and spotting. Fire started in a peat bog; it continued into

cutover areas and then spread into spruce-fir stands.

November 4, 1965

- 18 Tuscorora Mt. (Pennsylvania), 550 acres burned; difficult mopup, fire broke out again on November 6.

April 5-6, 1967

- 19 White Ranch (Missouri), 2,050 acres burned with low vegetation in cured stage. Previously burned hardwood area with a large number of snags.

June 3, 1967

- 20 Clearwater (Minnesota), 800 acres burned with crowning and spotting. Fire started in cured low vegetation (grass, moss, and dry duff). It then burned through heavily stocked, pole size, spruce and fir stands.

April 19, 1968

- 21 Broad Mt. (Pennsylvania), 819-acre fire; "Governor issued a proclamation cautioning extreme fire danger." Unbroken scrub oak.

May 8, 1968

- 22 (Michigan), two fires of 1,570 and 4,692 acres, much crowning and spotting. Oak and jack pine.

March 19-22, 1969

- 23 (Missouri), eight large fires burned a total of 5,700 acres. Low vegetation in cured stage; mostly grass and second growth hardwoods burned.

March 31, 1971

- 24 (Missouri), eight large fires burned a total of 6,400 acres; 15,000 acres were burned across the State. Serious fires also reported in south Illinois. Mostly second growth hardwoods in late dormancy.

April 18, 1971

- 25 Manahawkin (New Jersey), 21,000 acres burned in 7 hours. Critical fires also reported in eastern Pennsylvania. Fire began in a grass field near the Pine Barrens region. It displayed extensive crowning as it moved into pitch pine.

May 14, 1971

- 26 Little Sioux (Minnesota), 15,000 acres burned with much crowning and long distance spotting. Sixty-five percent of area had been recently logged. The fuels included tall, dead, marsh grass and aspen and conifer stands.

These 26 fire situations include most of the well known fires that have occurred in the northeastern and north-central States since 1871 as well as situations judged especially difficult by State fire-control organizations. They do not represent all the critical fire situations that have occurred in these States, only those for which weather and fire behavior data were well documented. The selection emphasizes fires

since 1960 because personnel currently employed in fire-fighting organizations had first-hand experience in their containment.

INTERPRETATION OF RESULTS

The values of the three indexes before the 26 critical fire periods are tabulated in table 1. Almost all the median and mean

Table 1.--Immediate weather conditions and index values at the time of fire start

Map No.	Observation station(s) or climatic division(s)	Weather conditions			Indexes		
		Temperature °F	Relative humidity Percent	Wind speed M.p.h.	Palmer	K-B	BUI
1.	Madison, Wisconsin		24		1-3.79	300	101
	Sturgeon Bay, Wisconsin	63		12			
2.	Chicago, Illinois	85	24	22		394	80
3.	Lansing, Michigan	78	37	12	1-3.04	381	60
4.	Thornville, Michigan	99	40	34	1-4.93	435	80
5.	Sandy Lake, Minnesota	90	28		1-9.15	438	198
	St. Paul, Minnesota			20			
6.	Cloquet, Minnesota				1-2.46	246	66
	Duluth, Minnesota	76	31	265			
7.	Coastal Maine				-3.00		
	Portland, Maine	82	36	327		580	100
	Bar Harbor, Maine					510	82
8.	Coastal Maine				-2.50		
	Portland, Maine	72	47	16		98	46
9.	Eastern Ozarks, Missouri				-2.20		
	Salem, Missouri	75	44	8		622	104
10.	Coastal Maine				-2.43		
	Portland, Maine					160	68
	At fire	86	20	12			
11.	East-central Minnesota				-2.15		
	Duluth, Minnesota	80	27	20		21	32
	North-central, Minnesota				-2.34		
	Moose Lake, Minnesota	89				32	
	Park Rapids, Minnesota	93		50		38	
12.	Northeast Minnesota				-1.38		
	Duluth, Minnesota	77	22	14		48	38
	Winton, Minnesota					62	
	Green Bay, Wisconsin	74	26	10			54
13.	Southern New Jersey				-1.50		
	Atlantic City, New Jersey	79	15	25		150	78
	Pemberton, New Jersey					155	
	Northeast West Virginia				-1.00		
	Romney, West Virginia					218	
14.	South-central Mountains Pennsylvania				-4.57		
	Pittsburg, Pennsylvania	70	16	4		567	35
	Altoona, Pennsylvania					532	
15.	Northwest Lower Michigan				-1.54		
	Traverse City, Michigan	72	31	450		7	10
	Central Lower Michigan				-1.86		
	Northeast Lower Michigan				-2.74		
16.	Southwest West Virginia				-2.75		
	Charleston, West Virginia	70	20	20		550	75
17.	Coastal Maine				-4.69		
	Mitten, Maine	78	30	18			88
	Jonesboro, Maine					530	
	Ellsworth, Maine					580	
18.	Mid-Susquehanna, Pennsylvania				-2.68		
	Harrisburg, Pennsylvania	66	26	16		177	41
19.	Eastern Ozarks, Missouri				-1.34		
	West Plains, Missouri	86	24	18		258	63
	Rolla, Missouri					155	
20.	Northeast Minnesota				-0.52		
	Isabella, Minnesota	79	26	16		60	56

Table 1 continued on next page

Table 1 continued

Map No.	Observation station(s) or climatic division(s)	Weather conditions			Indexes		
		Temperature °F	Relative humidity Percent	Wind speed M.p.h.	Palmer	K-B	BUI
21.	East-central Mountains, Pennsylvania Cressona, Pennsylvania Allentown, Pennsylvania	73	29	10+	-1.63		67
						101	
22.	Northwest Lower, Michigan Houghton Lake, Michigan	65	52(1 p.m.) 24(4 p.m.)		+1.05	50	40
	At fire			15+			
23.	Eastern Ozarks, Missouri Summerville, Missouri Fremont Tower, Missouri Eminence, Missouri	79	17	13	-0.32	30	49
24.	South-central Missouri Salem, Missouri	73	14	21	-1.00	28	⁵ 55
25.	Southern New Nersey Tuckerton, New Jersey Coastal New Jersey Cedar Bridge, New Jersey	70	23	⁶ 19	-0.67 -0.73	50	52
26.	Northeast Minnesota Ely, Minnesota Cook, Minnesota Winton, Minnesota	76	15	16	+2.77 ¹ -1.23		45
						55	

¹Values computed for a single station and not a climatic division.

²Winds were fire induced.

³Wind was the highest of the day.

⁴Highest wind observations at fire.

⁵Ranged from 42 to 63 across the fire area.

⁶Wind gusts to 60 at fire.

values of the individual spring and autumn sets in figures 2, 3, and 4 are very close (table 2). Correlation (N=26) between the indexes are significant at the 1 percent level as follows:

	Palmer	K-B	BUI
Palmer	--	--	--
K-B	-0.62	--	--
BUI	-0.67	0.56	--

However, an appreciable portion of the variability is not accounted for; this emphasizes that all three indexes respond somewhat differently to various phases of the water exchange process. We did not attempt to compare variability by computing the coefficient of variation because of the nature of the number scales in the three systems.

Our data re-emphasizes that long-term moisture deficiency in itself cannot be used to forecast critical fire situations. If the smaller fuels are wet or green and winds are calm, serious fires usually will not occur at any time of year. Most critical fires are caused from a combination of factors that occur in conjunction with drought conditions. Consequently, it is not possible to establish precise "threshold values" at which critical fire situations may develop although most of the 26 fire

Table 2.--Median, mean, standard deviation, and 90th percentile levels of 3 indexes in the spring and fall before 26 critical fire periods

SPRING (N=14)				
Index	Median	Mean	Standard deviation	90th Percentile levels
BUI	51	50	17	14 to 86
Keetch-Byram	52	82	68	0 to 227
Palmer	-1.49	-1.0	1.4	1.98 to -3.98
FALL (N=12)				
BUI	80	86	42	0 to 178
Keetch-Byram	438	439	145	123 to 755
Palmer	-3.1	-3.7	2.0	0.66 to -8.1

situations we examined began with BUI values above 30 in the spring and well above 40 in the fall (fig. 2). None of them developed when the Palmer Index was less than -2.2 in autumn (fig. 4). The other three seasonal data groupings are more ambiguous (figs. 3 and 4).

Response times are often quite different when we compare the three systems (fig. 5). For example, in the late fall of 1952 (figure 1, No. 9) a proclamation by the governor of Missouri, followed by similar Forest Service action, closed all woods and forests in that State to the public, the only time this action has ever been taken there. The people of the eastern Ozarks

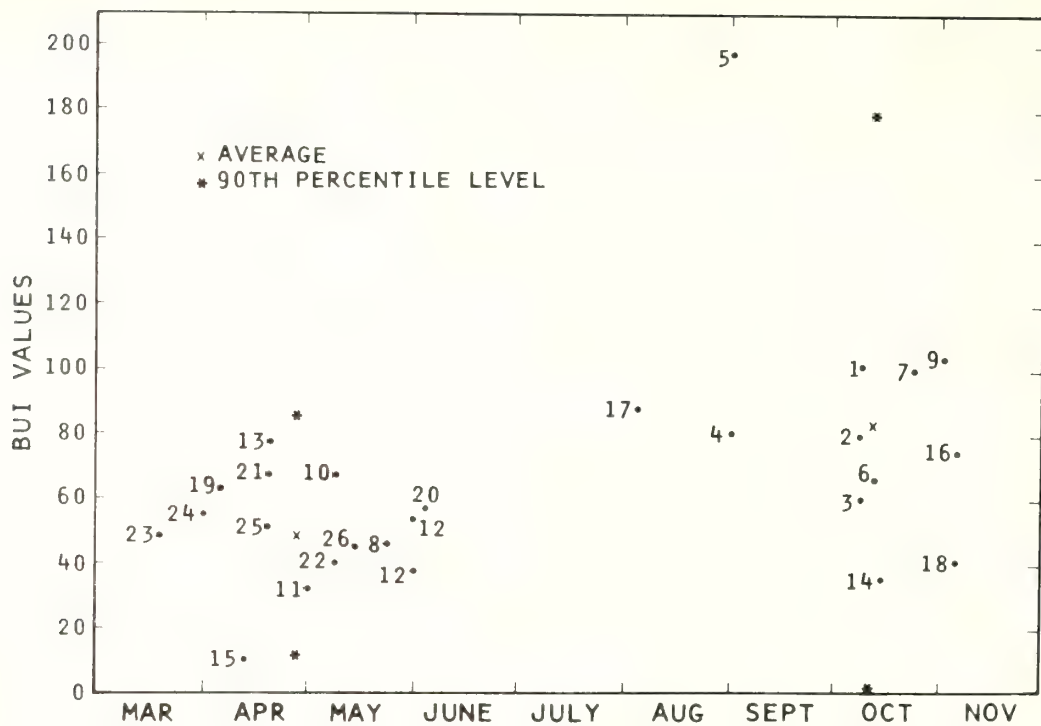


Figure 2.--BUI values before the critical fire periods shown in figure 1.

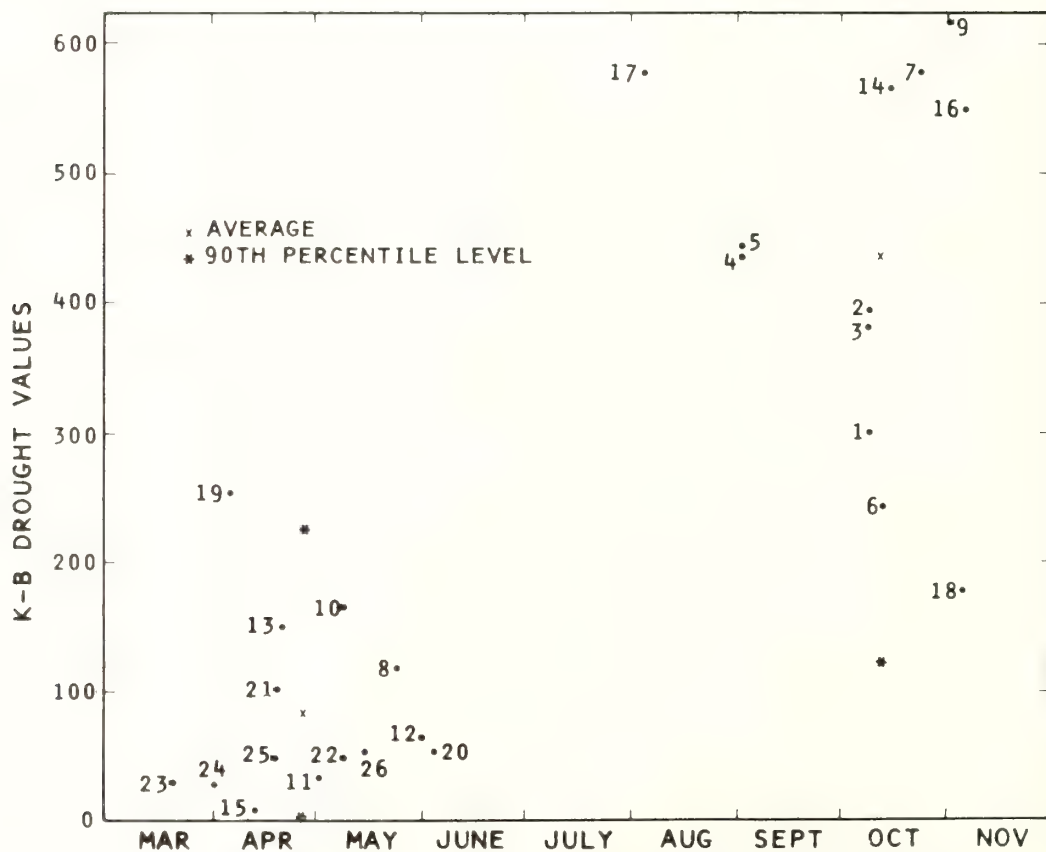


Figure 3.--K-B Drought values before the critical fire periods shown in figure 1.

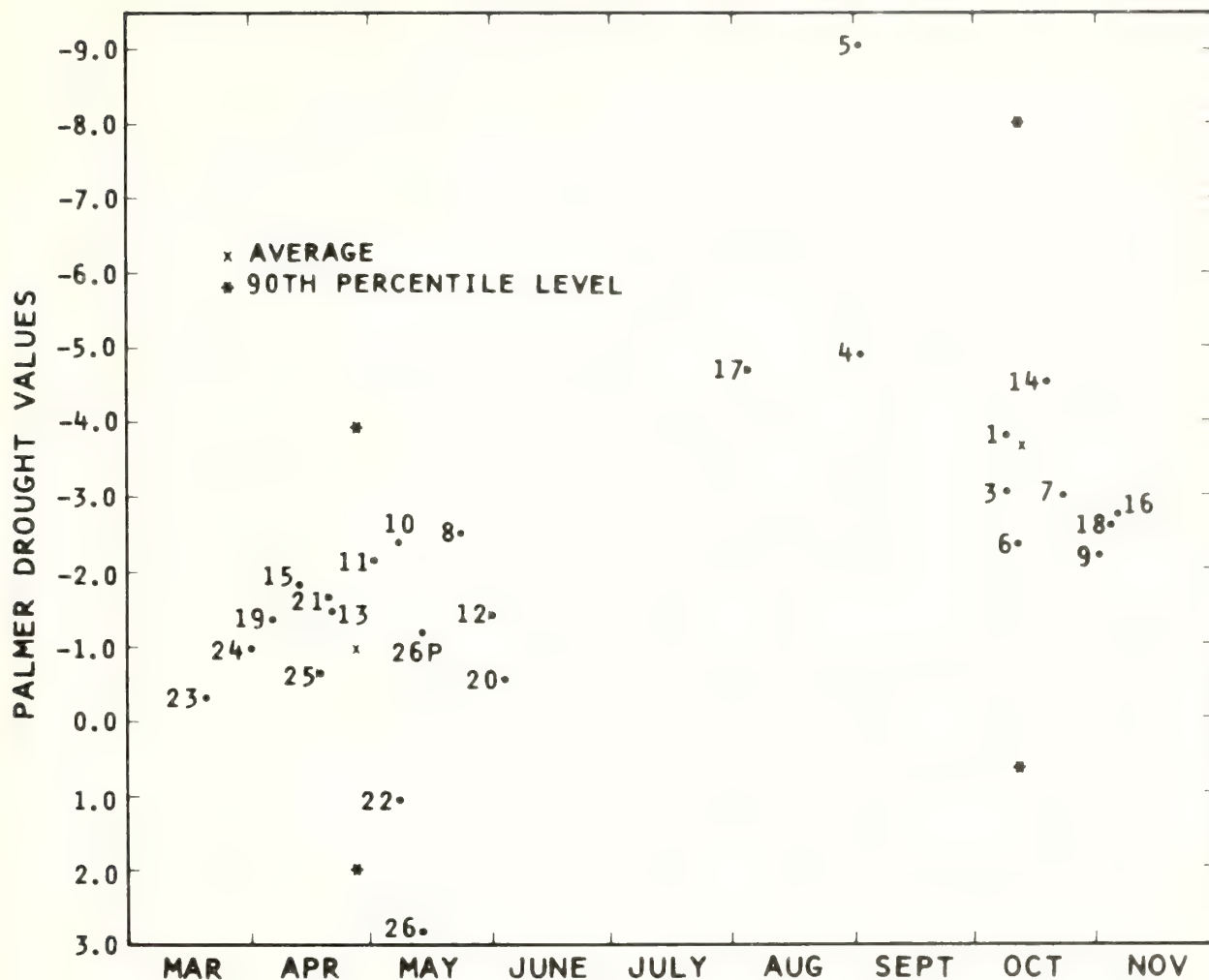


Figure 4.--Palmer Drought values before the critical fire periods shown in figure 1. For May 14, 1971 (figure 1, No. 26), two values are given: the second (26 p.) was computed using point-source observations taken near the fire area.

considered that drought and fire danger period to be the worst in memory. The Palmer Index classed the Missouri area as "very wet" through the spring of 1952. Consequently the Palmer system, because it reacts slowly, only rated this area as mild-to-moderate drought by autumn. On the other hand, the Keetch-Byram system assigned the most critical value of all 26 fire situations examined (622) and the BUI assigned the second most critical value (104). The Keetch-Byram and the BUI systems appear to give more realistic assessments of the true 1952 fire potential in Missouri because both were designed to respond more rapidly to fast changing situations than the Palmer Index.

All three indexes produce markedly different sets of spring vs. fall values. Spring-fall value differences are very pronounced in the Keetch-Byram system and obvious in the Palmer Drought Index. These differences are not as distinct in the BUI. Index values are not as high in spring as in autumn because causal factors assume varying degrees of importance from season to season. For example, critical fires almost always occur in the spring when ground vegetation is in the cured stage and this is often the decisive factor in that season, not the soil moisture deficit.

In spring, many large-fire situations develop without an appreciable increase in

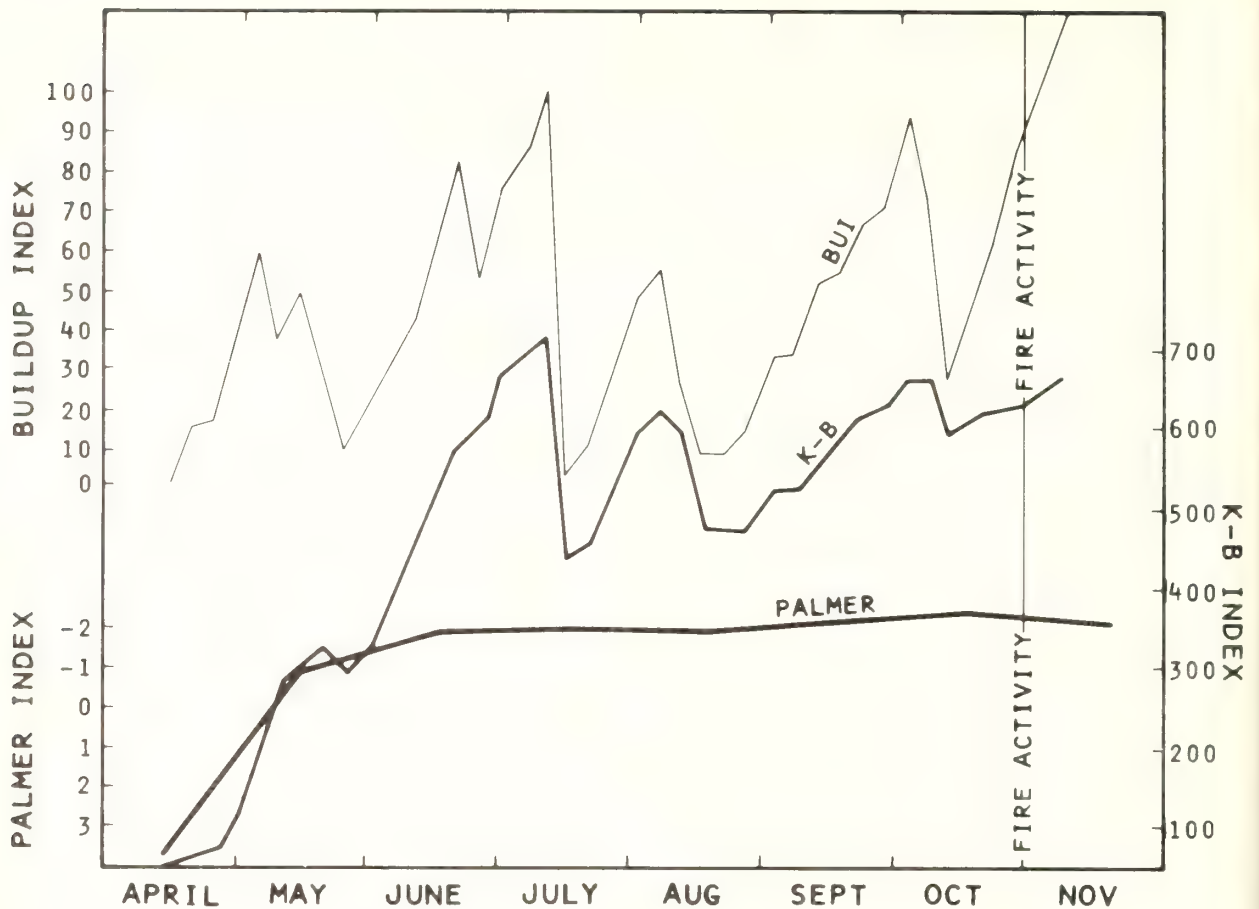


Figure 5.--Values of BUI, K-B Drought, and the Palmer Drought Indexes during the 1952 fire season in Missouri, including the November 1 fires (figure 1, No. 9). Palmer Drought values are given for the East Ozark division. The BUI and K-B Drought values were computed using data from the Salem station.

the Keetch-Byram Index. Apparently this is because the index does not increment unless afternoon temperatures are above 50°F. There is usually little or no carryover from year to year in K-B values, even in the southern sectors of the north-central and northeastern States (fig. 6). In Missouri, for example, K-B values are usually at their lowest during the early-spring, fire season. This type of index is obviously more appropriate for late summer and fall evaluations of danger situations.

Because the Palmer system is normalized, its average values are near zero for any given month of the year (fig. 7). A zero value indicates that soil conditions are near the normal for that geographic area. For Missouri's three spring fire situations

(figure 1, Nos. 19, 23, and 24), the Palmer values show near normal to mild drought (Appendix III), not an indication of potentially serious conditions (fig. 7). The Keetch-Byram system produced near seasonal normal values for two of these same critical fires (fig. 6). Only the BUI showed a consistent danger value in all three situations (fig. 8); it gave extreme values that might be expected 1 year in 20.

The Keetch-Byram Index may do an adequate job of representing moisture conditions at lower levels throughout the year, but the importance of moisture to fire potential at this level changes with season. On spring days when temperatures are below 50°F, moisture loss from lower layers will probably be negligible, but evaporation

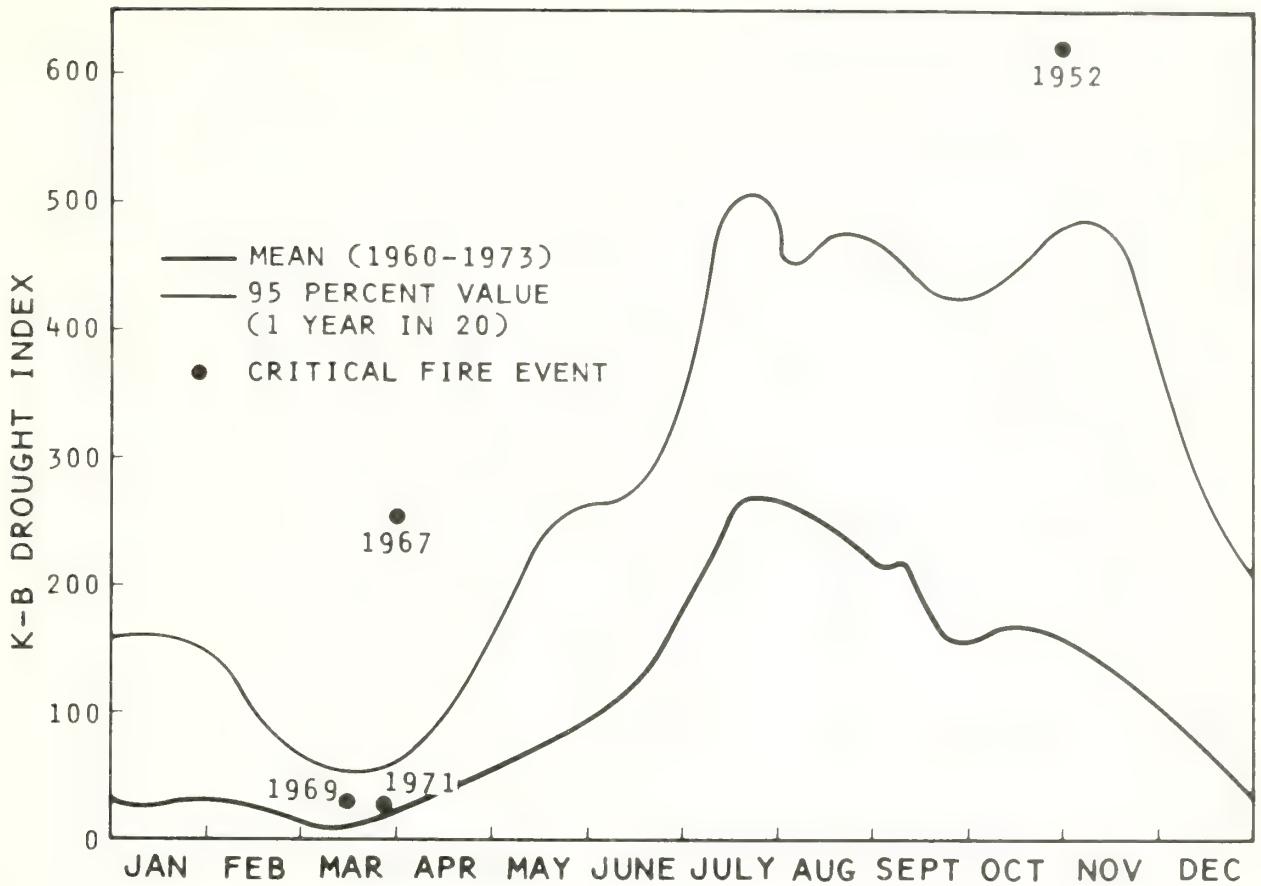


Figure 6.--K-B Drought Index for Salem, Missouri, showing the 1960-1973 mean values and the extreme values to be expected 1 year in 20. Values are also shown for the critical Missouri fire periods during 1952, 1967, 1969, and 1971 (figure 1, Nos. 9, 19, 23, 24).

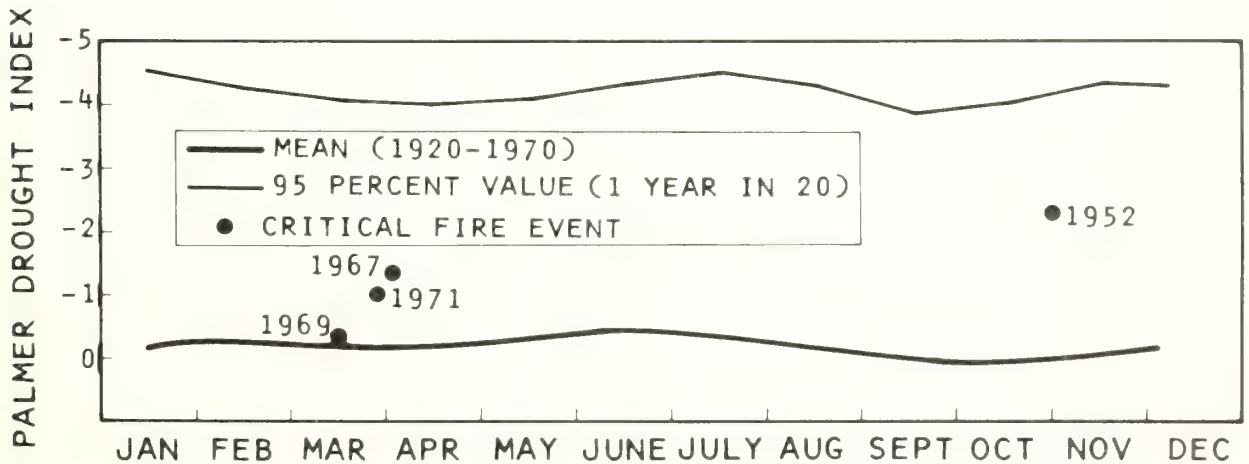


Figure 7.--Palmer Drought Index in the Eastern Ozarks (Missouri) showing the 1920-1970 mean values and the extreme values to be expected 1 year in 20. Values are also shown for the critical Missouri fire periods during 1952, 1967, 1969, and 1971 (figure 1, Nos. 9, 19, 23, 24).

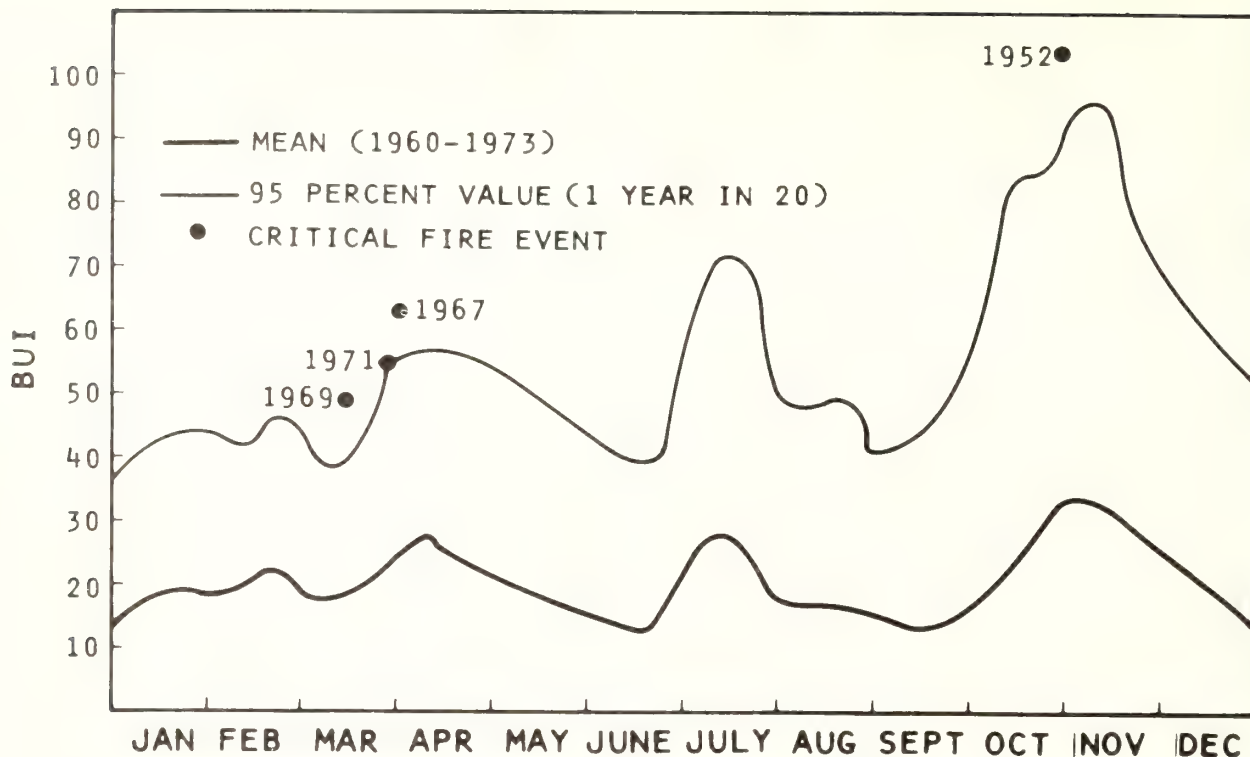


Figure 8.--BUI at Salem, Missouri, giving the 1960-1973 mean values and the extreme values to be expected 1 year in 20. Values are also shown for the critical Missouri fire periods during 1952, 1967, 1969, and 1971 (figure 1, Nos. 9, 19, 23, 24).

from the upper levels may be important. Inasmuch as vegetation is usually dormant in spring, the effects of transpiration are nil and moisture at lower levels is usually of no concern. During spring, moisture at surface and in the extreme upper layer largely determines the condition of the available fuels.

Later in the year, living vegetation draws moisture from the upper and lower levels and other physical phenomena cause water loss from all layers. Therefore, it appears that a measure of long-term progressive drying for the late growing season should focus on both the upper and lower layers as a source of moisture.

CONCLUSIONS

Any system that is dependent upon one fixed depth of soil horizon to indicate fire danger is not usable throughout the fire season in the north-central and north-eastern States. Therefore, a danger system

employing a multilayer soil model having varying response features would be optimum but highly complex.

Given a choice of realistic alternatives, it appears that a litter-duff index having rapid response features gives best results in the spring. An index having slower response features that considers a greater depth of soil horizon appears to be satisfactory during the late summer-fall fire season, especially if it is used in combination with a litter-duff model. Therefore, these data reinforce the decision of those modelers who have opted for a dual-entry system in accounting for long-term moisture deficiency.

Such a system does not include the direct contribution of large surface fuels and living vegetation. Indirectly, however, the relative moisture status of these materials may be reflected by the soil moisture trends. The moisture content of living vegetation is partially determined by the availability of moisture to root systems, while

the water content of large surface fuels responds to the same environmental stimuli as does soil water. Although extensive investigation is needed to represent the actual integrated response of the total fuel complex to drought, immediate needs appear best met by a two-layer system.

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APPENDIX I.--THE BUILDUP INDEX

The Buildup Index in the 1964 National Fire Danger Rating System is defined as "a number expressing the cumulative effects of a daily drying factors and precipitation in fuels having a 10-day timelag constant."¹ It appears, however, that it might be more representative of fuels having a 5-day timelag constant. The designers of the BUI used a 10-day timelag because they hoped it would equal the drying rate for the average forest floor; thus it would have significance nationally. They felt the index represented conditions in the upper 2 to 3 inches of litter-type fuels.

The BUI is a numerical expression of the accumulated rate of moisture absorption-desorption. A numerical factor of 5 (a

¹Timelag is defined as the time necessary for a fuel particle to lose approximately 63 percent of the difference between its initial moisture content and its equilibrium moisture content.

drying factor) is assigned for a standard drying day (80°F, 20 percent relative humidity). A colder or more humid day is assigned a lesser number. A hotter or dryer day is assigned a greater number.

Precipitation reduces the value of the BUI as follows:

$$BUI = -50(\text{LOG}_e(1.0 - (1.0 - \text{EXP}(\frac{-BUO}{50}))\text{EXP}(-1.175(P - 0.1))))$$

where BUO = yesterday's BUI and P = past 24-hour precipitation. The BUI is then adjusted by adding the drying factor.

This index is similar to the Timber Buildup used in the California Wildland Fire Danger Rating,² but a dry-wet bulb temperature measurement is used to arrive at a daily drying factor. In the Wildland System a timber buildup factor is derived from daily fuel-stick moisture. These factors were accumulated to provide the drying portion of Timber Buildup.

"As the Buildup Index increases, there should be more fuel burning and greater fire persistence. These changes should be reflected in the difficulty of handling fires, and thus call for stepped up preparedness beyond what would be necessary for a change in spread index alone," according to Keetch.³

Where snow often covers the ground all winter, the BUI usually starts anew each spring. In southern areas values can carry through the winter. In some States, Missouri, for example, users reported that the numbers did not seem to have the same meaning in spring as they did in autumn.

Calculation requires: (1) book tables (Nelson 1964), (2) wet-dry bulb temperatures, and (3) 24-hour precipitation amounts. Some fire control units in southeastern States use the following rule of thumb: the herbaceous stage changes from green to transition when BUI values reach 50 and changes to

²Unpublished report by the USDA For. Serv., Pac. Southwest For. and Range Exp. Stn. 1962.

³Development of the national fire danger rating system: basic structure and spread phase. 82 p. Unpublished manuscript on file at the Southeast. For. Exp. Stn., Asheville, North Carolina.

cured when they reach 100. This appears to have been based upon administrative judgment, not empirical evidence.

Advantages of the BUI

1. The system is easy to compute and provides a continuous record because it is updated daily.
2. Point source computation permits the estimation of values for small areas. It is not restricted to a bounded land area.

Disadvantages of the BUI

1. A point source computation will not always be representative of a larger area, although Gerrie (1969) found that single stations are representative of the Canadian areal drought index about 90 percent of the time.
2. The index requires relative humidity observations, which are more difficult to obtain than temperatures or precipitation amounts. Relative humidity does not have conservative meteorological properties, and its measurement is more subject to observational error.

APPENDIX II.--KEETCH-BYRAM DROUGHT INDEX

The Keetch-Byram Drought Index attempts to measure the amount of precipitation necessary to return the soil to full field capacity. It is a closed system ranging from 0 to 800 units and represents a moisture regime from 0 to 8 inches of water through the soil layer. At 8 inches of water, the Keetch-Byram Index (K-B) assumes saturation.

The expression for the drought equation takes the general form:

$$dQ = \frac{[800-Q][0.968\text{EXP}(0.0486T)-0.83]d\tau}{1 + 10.88 \text{EXP}(-0.0441R)} \times 10^{-3}$$

where dQ = the drought factor, Q = the moisture deficiency, T = the maximum temperature °F, R = the mean annual precipitation in inches, and τ = the time in days during which soil-duff has been losing moisture. The time increment is usually set equal to 1 day.

Routine calculation requires: (1) the above equation or book tables (Keetch and Byram 1968), (2) daily maximum temperature or the 2:00 p.m. temperature, and (3) the 24-hour precipitation amount.

Advantages of the Keetch-Byram Index

1. The system is easy to compute and provides a continuous record because it is updated daily.
2. Point source computation allows one to estimate values for small areas. It is not restricted to a bounded land area.
3. It does not require a routine schedule of meteorological observations that are difficult to obtain.

Disadvantages of the Keetch-Byram Index

1. Point source computation will not always be representative of a larger area, although Gerrie (1969) found that single stations are representative of the Canadian areal drought index about 90 percent of the time.
2. Computation often produces values reflecting soil field capacity during the spring fire season, but these do not necessarily indicate whether fire conditions are critical.

APPENDIX III.--THE PALMER DROUGHT INDEX

This index measures a departure from normal and is the only one of the three that has been normalized. Classes for dry periods follow:

<i>Monthly index value</i>	<i>Class</i>
4.00 and above to 0.50	Extremely wet to incipient wet spell
0.49 to -0.49	Near normal
-.50 to -.99	Incipient drought
-1.00 to -1.99	Mild drought
-2.00 to -2.99	Moderate drought
-3.00 to -3.99	Severe drought
-4.00 and below	Extreme drought

Monthly data were used to determine drought values by the standard Palmer methodology. Results seem realistic because the system responds rather slowly to change. Palmer (1965), after comparing output using weekly and monthly computations, reported, "the weekly data provide more detail and apparently get just a little closer to a realistic measure, but for climatological purposes the differences are slight." Weekly analysis makes it possible to keep current with the progress of drought on an operational basis.

The soil is divided into two arbitrary layers, and the moisture loss is calculated as follows:

$$L_s = S_s \text{ or } (PE-P),$$

(whichever is smaller), and

$$L_u = (PE-P-L_s) \frac{S_u}{AWC}, L_u \leq S_u$$

where L_s = moisture loss from surface layer, S_s = available moisture stored in surface layer at start of month, PE = potential evapotranspiration for the month, P = precipitation for the month, L_u = loss from underlying levels, S_u = available moisture stored in underlying levels at start of month, and AWC = combined available capacity of both levels.

Calculation requires: (1) a large number of constants (Palmer 1965), (2) maximum and minimum temperature (weekly or monthly means), and (3) weekly or monthly precipitation amounts. A computer program has been written that outputs these data for single station analysis.⁴

Advantages of the Palmer Index

1. It is a highly complex system that considers an impressive array of features such as the estimated run-off, the potential recharge, and three severity indexes.

2. It is presently computed weekly for all climatic divisions of the country by NOAA through most of the fire season and published periodically in a NOAA-USDA joint publication, *Weekly Weather & Crop Report*.

3. The values are normalized based on the 1930-1960 climatic period.

4. It does not require a routine schedule of meteorological observations that are difficult to obtain.

Disadvantages of the Palmer Index

1. Because this is an extremely complicated system, hand computation is difficult for those lacking an extensive background in drought analysis.

2. Climatic division values are not always representative of smaller inclusive areas. During the Little Sioux fire in 1971, for example, the index value for the Minnesota northeast climatic division was +2.77. A point source computation for the immediate fire area produced a value of -1.23 (table 1).

3. A final index value requires a probability computation. This probability term allows the user to select a drought value given three choices: (1) What is the severity index if a wet spell is becoming established? (2) What is the severity index if drought is becoming established? (3) What is the severity index for any wet spell or any drought that has become definitely established? The index of drought (or wet spell) severity is unassigned when the probability term is between 0 and 1.0. The proper choice is easily determined on a climatological basis (after the fact). Operationally, however, the choice is much more difficult to make, and the selected index value must be considered a best guess on a real time basis. Operationally this is not entirely a detriment because it also provides valuable options. It may make the system more difficult to use as a simple descriptive tool, yet it provides a wider range of autonomy and allows a predictive capability.

⁴Main, W. A., and D. A. Haines. *Point source, computer program for the Palmer Drought Index*. 12 p. Unpublished manuscript on file at the North Cent. For. Exp. Stn., East Lansing, Michigan.

Haines, Donald A., Von J. Johnson, and William A. Main.

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Values of the Palmer Drought Index, the Keetch-Byram Drought Index, and a Buildup Index are calculated for 26 critical fire situations in the north-central and north-eastern States. The paper examines the response characteristics of these Indexes, representative of different moisture regimes, relative to fire danger.

OXFORD: 431.5:431.2(74/77). KEY WORDS: Palmer Drought Index, Keetch-Byram Drought Index, drought, fire-danger, fuel-moisture.

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1976. An assessment of three measures of long-term moisture deficiency before critical fire periods. USDA For. Serv. Res. Pap. NC-131, 13 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

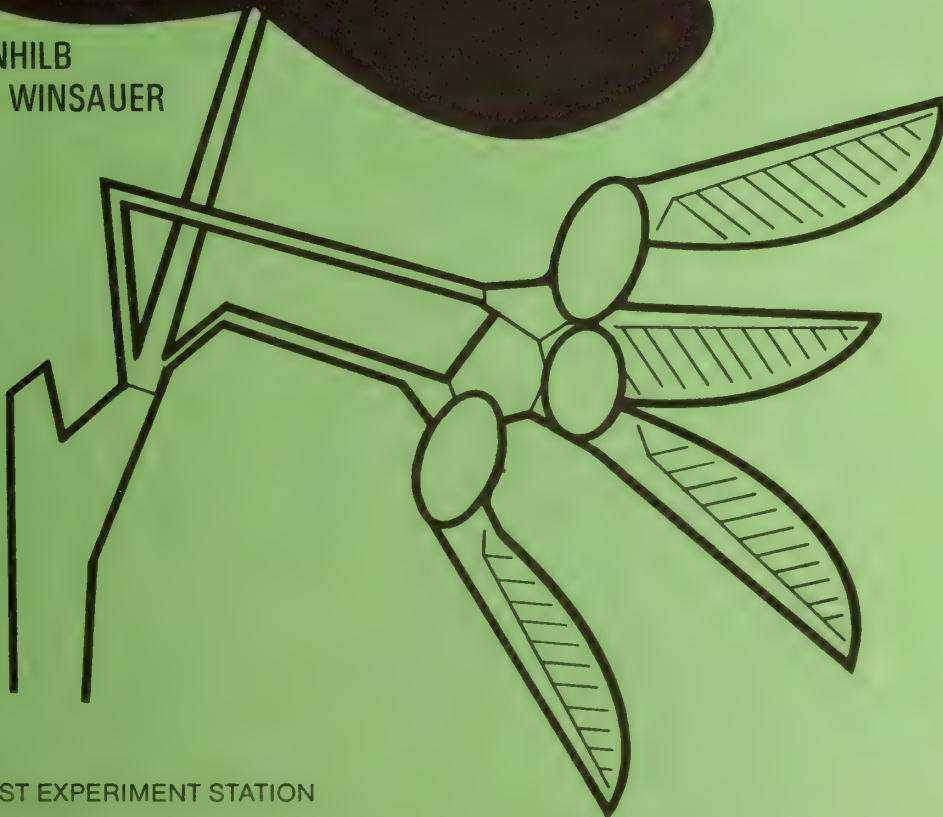
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Sugar Maple: Tree and Bole Weights, Volumes, Centers of Gravity and Logging Residue.

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SUGAR MAPLE: TREE AND BOLE WEIGHTS, VOLUMES, CENTERS OF GRAVITY, AND LOGGING RESIDUE

H. M. Steinhilb and Sharon A. Winsauer

A trend toward mechanization of the skidding and loading phases of logging operations has been evident during the past decade. Logging equipment is being developed to handle tree-length boles or entire trees. Designers of such harvesting machines need information on the weight, volume, and center of gravity of trees and boles.

There is also a trend toward more complete utilization of the tree. Present systems tend toward chipping logging residue, and even entire trees, in the woods by mobile machines. Here again, logging equipment design engineers and foresters need estimates of the cubic volume and the weights of logging residue, trees, and boles.

Such information is available for spruce, balsam fir, red pine and aspen.^{1/ 2/} But data are also needed for sugar maple and other dense hardwoods that are being increasingly used for wood chips. Because sugar maple is the most prevalent species in the northern hardwood timber type, we recently developed the data reported here.

THE STUDY

The research was conducted in a northern hardwood sawtimber stand located at the Ford Forestry Center, Michigan Technological University, Baraga County, Michigan. Data

¹ Steinhilb, H. M., and John R. Erickson. 1970. *Weights and centers of gravity for quaking aspen trees and boles*. USDA For. Serv. Res. Note NC-91, 4 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

² Steinhilb, H. M., and John R. Erickson. 1972. *Weights and center of gravity locations for red pine, white spruce, and balsam fir trees and boles*. USDA For. Serv. Res. Pap. NC-75, 7 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

were collected from 137 sugar maple trees: 58 of pulpwood size and 79 saw log trees. The sample trees ranged from 5 to 24 inches d.b.h. and from 45 to 90 feet in total height.

Field Procedure

Each tree was numbered and its d.b.h. measured to the nearest 0.1-inch. Then it was carefully felled to minimize breakage and loss of limbs. Within 24 hours after felling all portions of each tree were weighed with a weight transducer mounted on a free-swing sling attached to a fork-lift (fig. 1).

Pulpwood trees (trees less than 12 inches d.b.h.) were first weighed whole by suspending them from the weight transducer. A point was marked on each stem directly below the apex of the sling as the center of gravity. Then the tree was limbed and topped to a 4-inch diameter outside the bark; the bole was suspended again, weighed, and its center of gravity marked. Pulpwood tree diameters were measured outside the bark to the nearest 0.1 inch at the stump, at 2 and 4 feet from the butt, and at 8-foot intervals thereafter to a top diameter of 4.0 inches outside the bark. The length of any residual portion of the bole above the last 8-foot section was also measured. Total bole length from the butt to a 4-inch upper diameter point was recorded, together with length of the entire tree.

Felled saw log trees (trees 12 inches d.b.h. or larger) were bucked into saw logs to a 10-inch top according to standard commercial logging practice.^{3/} Each of the logs and bole sections and the top of each tree were weighed to the nearest 0.5 pound. Center of gravity was not established for saw log trees.

³ Official grading rules for northern hardwood and softwood logs and tie cuts. Northern Hardwood and Pine Manufacturers Association, Inc., Green Bay, Wisconsin. 1968.

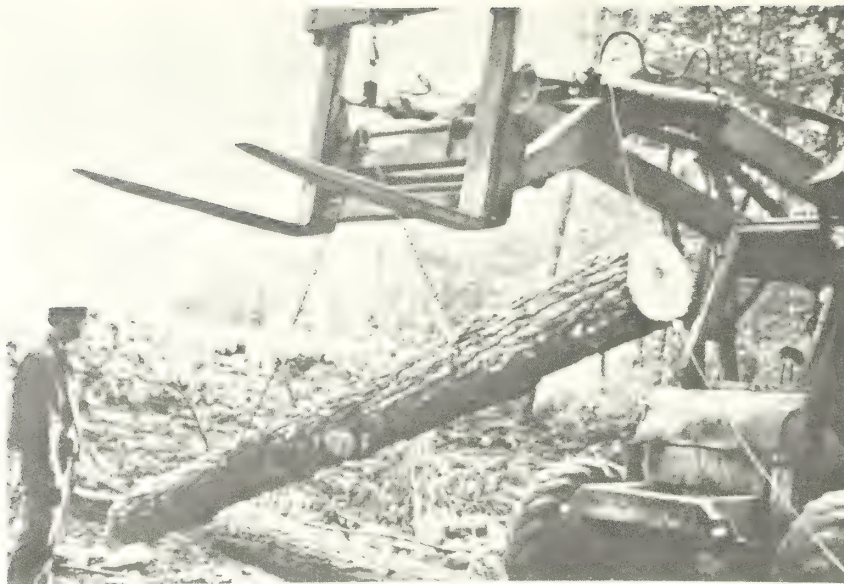


Figure 1.--Weighing trees and boles.

Each log, together with any cull sections within the merchantable bole, was scaled with the Scribner Decimal C log rule to obtain both gross and net board foot volume. To determine the cubic foot volume of the bole, diameter outside the bark and bark thickness were measured at both ends of each log. The length, width, and butt diameter of the residual top were recorded.

Analytic Procedure

The cubic foot volume of the boles (including bark) was calculated from taper measurements.

The green weight per cubic foot for each bole was determined by dividing its total green weight by its calculated volume in cubic feet. The weight of the entire tree including the residue was then divided by the weight per cubic foot to obtain the approximate cubic foot volume of the entire tree.

The data were analyzed separately for pulpwood and saw log trees because bole length was defined differently for each class (4-inch top for pulpwood and 10-inch for saw logs) and because center of gravity was measured only for pulpwood

trees, and board foot volumes apply only to saw log trees. However, tree weight and tree cubic foot volume measurements were compatible for both classes, so regression equations for tree weight and tree cubic foot volume were obtained for all trees combined.

Both sets of data were analyzed similarly. Scatter plots were made of the desired dependent variables against the various probable independent variables. Promising relations were selected from the scatter plots, studied for homogeneity of variance, and further explored by running various weighted regressions and step-wise regressions. The final equations were selected according to goodness of fit, simplicity, and physical logic; preference was given to those variables that are normally measured in timber inventory or are easily obtainable.

For sawtimber trees, two equations for residue weight per M board feet were selected, one with bole length as the independent variable, the other with d.b.h. Although bole length provided a better fit with a smaller standard error of estimate, the d.b.h. equation is also given for the use of the field forester in those cases where bole length is not taken in the field.

The variance in weight and volume measurements increased as the diameter of the tree increased at a rate of approximately (d.b.h.)⁴. Therefore, the final equations were run as weighted regressions with a weighting factor of 1/(d.b.h.)⁴ to compensate for nonhomogeneity of tree weights, tree volumes, bole weights, bole volumes, and residue weights.

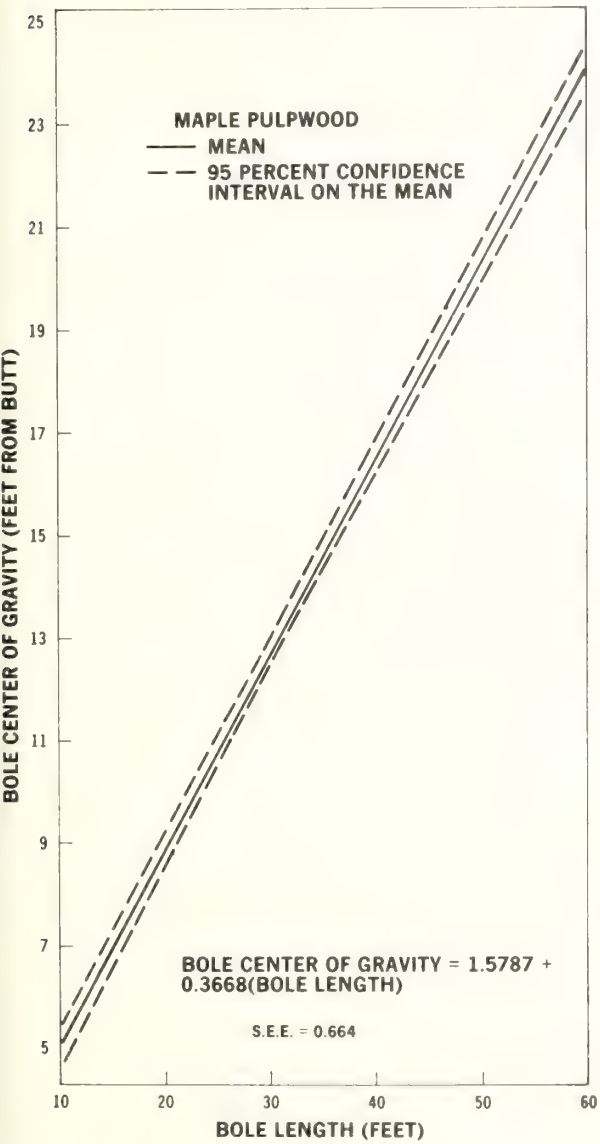


Figure 2.--Center of gravity of pulpwood boles.

RESULTS

The equations that resulted from this study were used to develop the tables and charts that follow. Although all this information has various potential uses, we particularly commend table 1 and figures 5, 6, 11, and 12 to foresters and tables 2 and 3 and figures 2 and 3 to equipment designers.

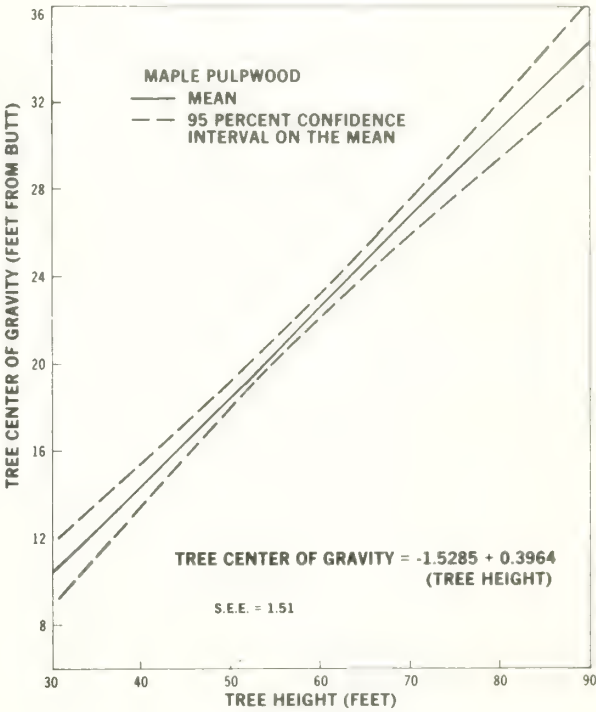


Figure 3.--Center of gravity of pulpwood trees.

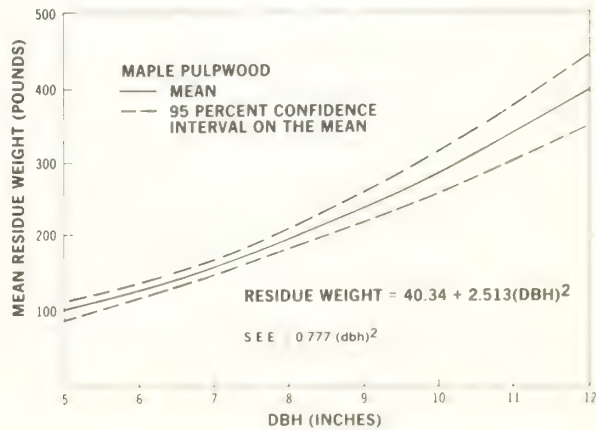


Figure 4.--Residue weight of pulpwood trees.

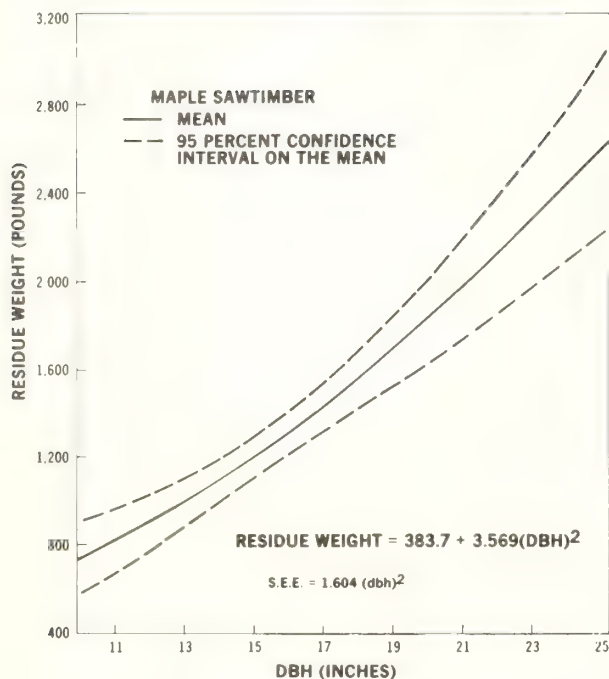


Figure 5.--Residue weight of sawtimber by d.b.h.

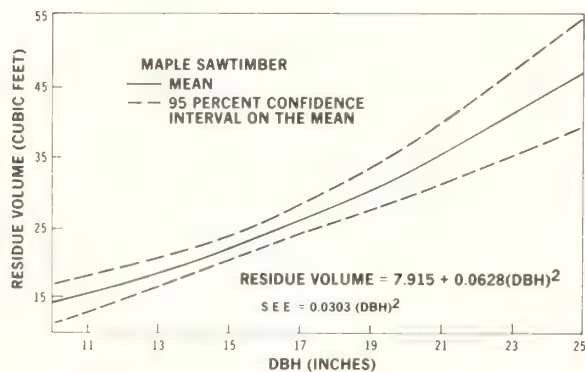


Figure 6.--Residue volume of sawtimber by d.b.h.

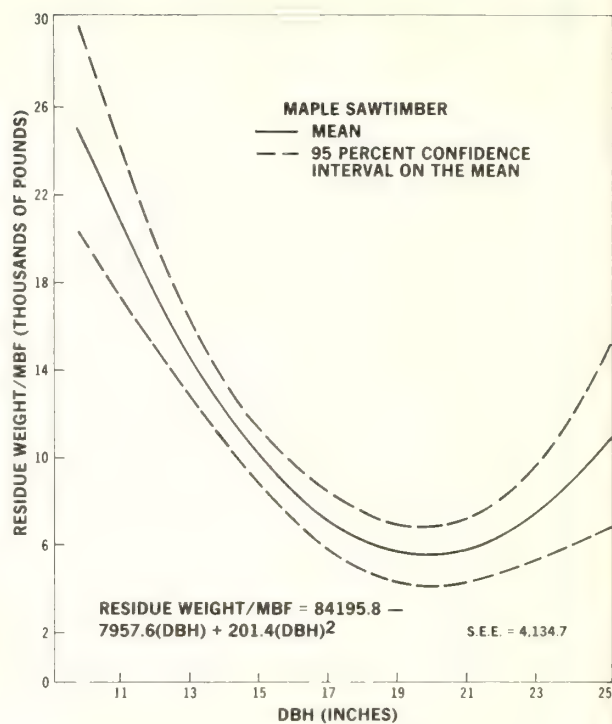


Figure 7.--Residue weight per thousand board feet of saw logs produced by d.b.h.

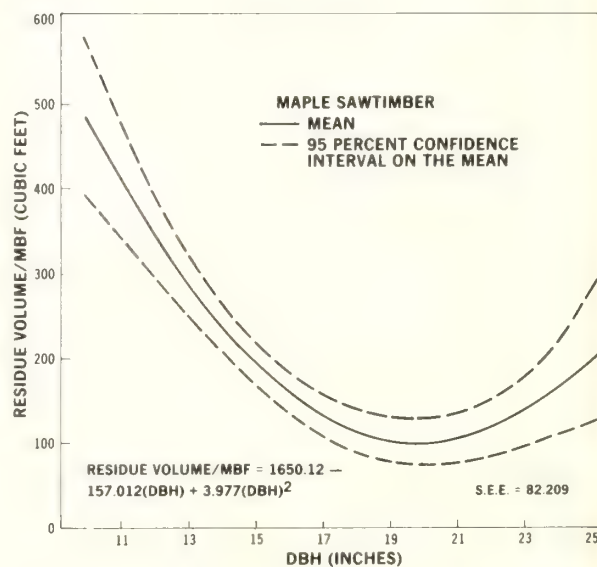


Figure 8.--Residue volume per thousand board feet of saw logs produced by d.b.h.

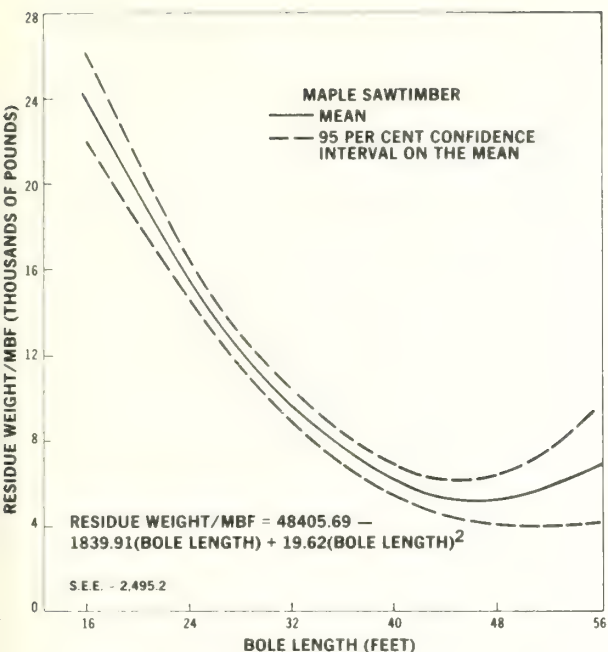


Figure 9.--Residue weight per thousand board feet of saw logs produced by bole length.

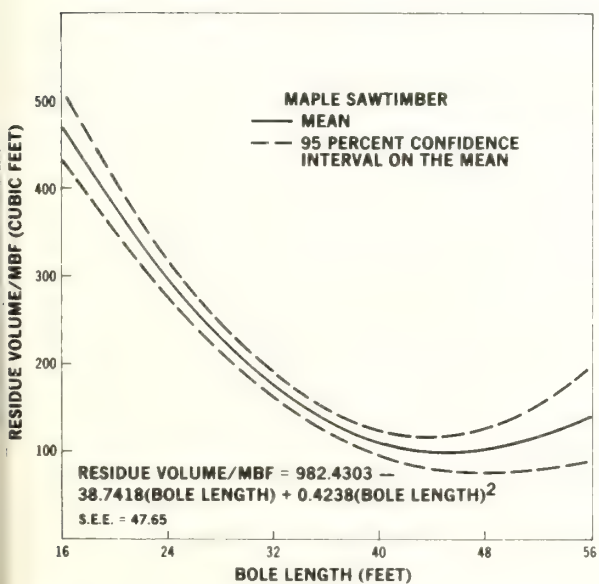


Figure 10.--Residue volume per thousand board feet of saw logs produced by bole length.

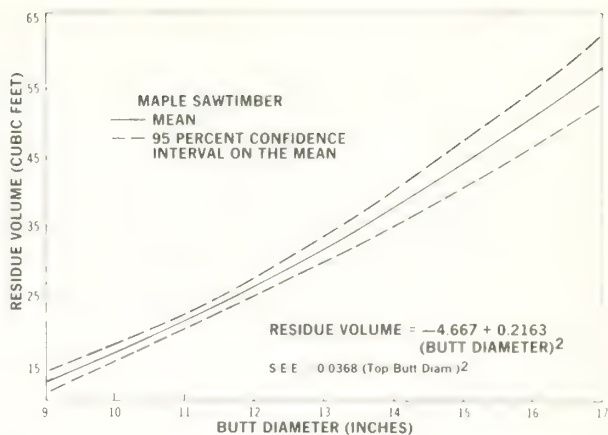


Figure 11.--Residue volume of sawtimber based on butt diameter of the top.

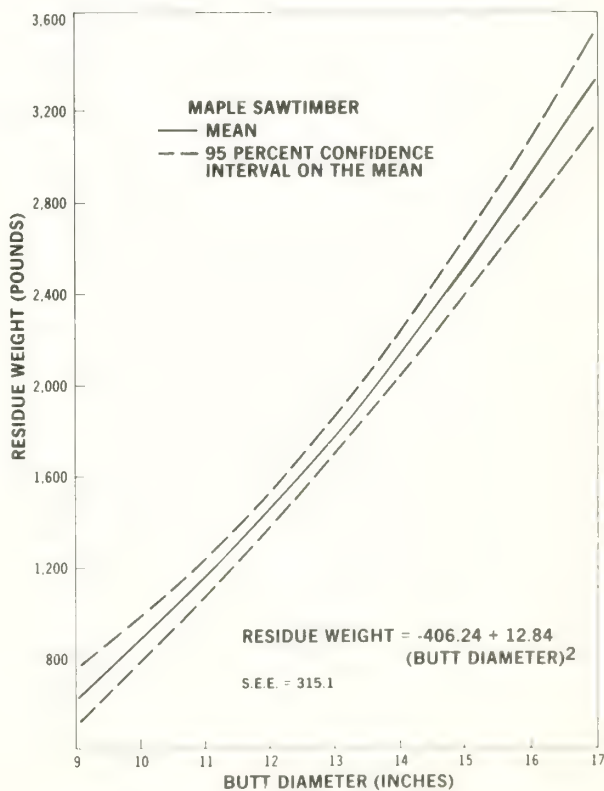


Figure 12.--Residue weight of sawtimber based on butt diameter of the top.

Table 1.--Tree weight and tree volume by d.b.h. and tree height (95 percent confidence intervals on the mean and individual estimates)

D.b.h.	Tree height (feet)											
	40		50		60		70		80		90	
	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume	Weight	Volume
	Pounds	Ft. ³	Pounds	Ft. ³	Pounds	Ft. ³	Pounds	Ft. ³	Pounds	Ft. ³	Pounds	Ft. ³
5	194.0 (±21.3) ¹ [+79.4] ²	2.82 (±0.39) [+1.45]	236.0 (±20.8) [+79.4]	3.59 (±0.37) [+1.44]	277.9 (±20.3) [+79.2]	4.37 (±0.37) [+1.44]						
6	267.8 (±20.4) [+112.1]	4.18 (±0.37) [+2.04]	328.2 (±19.8) [+112.0]	5.30 (±0.36) [+2.04]	388.7 (±19.5) [+112.0]	6.42 (±0.36) [+2.04]						
7	355.1 (±19.7) [+151.3]	5.80 (±0.40) [+2.80]	437.3 (±19.2) [+151.3]	7.31 (±0.34) [+2.75]	519.5 (±19.0) [+151.2]	8.83 (±0.34) [+2.75]	601.8 (±19.3) [+151.3]	10.35 (±0.35) [+2.75]				
8	455.8 (±19.2) [+196.9]	7.66 (±0.35) [+3.58]	563.2 (±19.1) [+196.9]	9.64 (±0.35) [+3.58]	670.6 (±19.6) [+197.0]	11.63 (±0.36) [+3.59]	778.0 (±20.6) [+197.1]	13.61 (±0.37) [+3.58]	885.3 (±21.8) [+197.2]	15.59 (±0.39) [+3.58]		
9	569.9 (±19.1) [+248.8]	9.76 (±0.34) [+4.52]	705.8 (±19.8) [+248.8]	12.28 (±0.36) [+4.53]	841.7 (±21.3) [+248.9]	14.79 (±0.39) [+4.53]	977.6 (±23.3) [+249.1]	17.30 (±0.42) [+4.53]	1,113.6 (±25.8) [+249.4]	19.81 (±0.47) [+4.53]		
10			865.2 (±21.6) [+307.0]	15.22 (±0.39) [+5.58]	1,033.0 (±24.3) [+307.2]	18.32 (±0.44) [+5.58]	1,200.8 (±27.5) [+307.5]	21.42 (±0.50) [+5.59]	1,368.6 (±31.2) [+307.8]	24.53 (±0.57) [+5.60]		
11			1,041.4 (±24.4) [+371.3]	18.48 (±0.44) [+6.75]	1,244.4 (±28.4) [+371.6]	22.23 (±0.52) [+6.75]	1,447.5 (±33.1) [+372.0]	25.98 (±0.60) [+6.76]	1,650.5 (±38.1) [+372.5]	29.73 (±0.69) [+6.77]		
12			1,234.4 (±28.3) [+441.9]	22.04 (±0.51) [+8.03]	1,496.0 (±33.8) [+442.3]	26.51 (±0.61) [+8.04]	1,717.6 (±39.8) [+442.7]	30.98 (±0.73) [+8.05]	1,959.3 (±46.1) [+443.4]	35.44 (±0.83) [+8.06]		
13			1,444.1 (±33.0) [+518.6]	25.92 (±0.60) [+9.43]	1,727.7 (±40.0) [+519.1]	31.16 (±0.73) [+9.43]	2,011.3 (±47.5) [+519.7]	36.40 (±0.86) [+9.45]	2,294.9 (±55.1) [+520.5]	41.64 (±1.00) [+9.46]	2,578.4 (±62.9) [+521.3]	46.88 (±1.14) [+9.47]
14			1,670.6 (±38.5) [+601.4]	30.11 (±0.70) [+10.94]	1,999.5 (±47.1) [+602.0]	36.18 (±0.85) [+10.94]	2,328.4 (±56.0) [+602.8]	42.26 (±1.02) [+10.96]	2,657.3 (±65.1) [+603.7]	48.34 (±1.18) [+10.97]	2,986.2 (±74.3) [+604.8]	54.42 (±1.35) [+11.00]
15			1,914.0 (±44.9) [+690.5]	34.60 (±0.81) [+12.55]	2,291.5 (±55.0) [+691.2]	41.58 (±1.00) [+12.56]	2,669.1 (±65.5) [+692.2]	48.56 (±1.19) [+12.58]	3,046.6 (±76.0) [+693.2]	55.53 (±1.37) [+12.59]	3,424.2 (±86.7) [+694.5]	62.51 (±1.57) [+12.62]
16					2,603.6 (±63.6) [+786.5]	47.35 (±1.16) [+14.30]	3,033.2 (±75.7) [+787.6]	55.29 (±1.38) [+14.32]	3,462.8 (±87.8) [+788.9]	63.22 (±1.59) [+14.33]	3,892.3 (±100.0) [+790.3]	71.16 (±1.81) [+14.36]
17					2,935.9 (±72.9) [+888.0]	53.49 (±1.32) [+16.14]	3,420.8 (±86.6) [+889.2]	62.45 (±1.57) [+16.16]	3,905.7 (±100.4) [+890.6]	71.41 (±1.82) [+16.19]	4,390.7 (±114.3) [+892.4]	80.37 (±2.07) [+16.22]
18					3,288.2 (±82.8) [+995.6]	60.00 (±1.51) [+18.10]	3,831.9 (±98.3) [+997.0]	70.05 (±1.79) [+18.13]	4,375.6 (±113.9) [+998.7]	80.09 (±2.06) [+18.15]	4,919.3 (±129.5) [+1,000.6]	90.14 (±2.35) [+18.19]
19					3,660.8 (±93.5) [+1,109.5]	66.88 (±1.69) [+20.16]	4,266.5 (±110.7) [+1,111.0]	78.08 (±2.01) [+20.20]	4,872.3 (±128.2) [+1,112.9]	89.27 (±2.32) [+20.23]	5,478.0 (±145.6) [+1,115.0]	100.47 (±2.65) [+20.27]
20					4,053.4 (±104.6) [+1,229.4]	74.14 (±1.90) [+22.35]	4,724.6 (±123.9) [+1,231.2]	86.54 (±2.24) [+22.37]	5,395.8 (±143.2) [+1,233.3]	98.95 (±2.60) [+22.42]	6,067.0 (±162.6) [+1,235.7]	111.35 (±2.95) [+22.46]
21					4,446.2 (±116.5) [+1,355.5]	81.77 (±2.11) [+24.64]	5,206.2 (±137.8) [+1,357.4]	95.44 (±2.50) [+24.67]	5,946.2 (±159.1) [+1,359.8]	109.12 (±2.89) [+24.72]	6,686.2 (±180.5) [+1,362.5]	122.80 (±3.28) [+24.77]
22					4,899.1 (±128.9) [+1,487.7]	89.77 (±2.34) [+27.05]	5,711.3 (±152.5) [+1,490.0]	104.78 (±2.77) [+27.08]	6,523.4 (±175.8) [+1,492.5]	119.79 (±3.19) [+27.13]	7,335.6 (±199.3) [+1,495.5]	134.80 (±3.62) [+27.19]
23							6,239.8 (±167.5) [+1,628.6]	114.55 (±3.05) [+29.61]	7,127.5 (±193.3) [+1,631.4]	130.95 (±3.51) [+29.65]	8,015.2 (±219.0) [+1,634.7]	147.35 (±3.97) [+29.71]
24							6,791.9 (±183.5) [+1,773.4]	124.75 (±3.33) [+32.24]	7,758.4 (±211.5) [+1,776.5]	142.61 (±3.84) [+32.29]	8,725.0 (±239.6) [+1,780.1]	160.47 (±4.35) [+32.25]

¹ Numbers in parentheses are confidence interval on the mean.

² Numbers in brackets are confidence interval on the individual estimates.

$$\text{Tree weight} = 26.21 + 0.1678 (\text{d.b.h.})^2 \quad (\text{tree height})$$

$$\text{S.E.E.} = 1.56 (\text{d.b.h.})^2$$

$$\text{Tree volume} = -0.283 + 0.0031 (\text{d.b.h.})^2 \quad (\text{tree height})$$

Table 2.--Fulwood tree bole weight and bole volume by d.b.h. and bole length (95 percent confidence intervals on the mean)

D.b.h.	Bole length (feet)											
	10		20		30		40		50		60	
	Weight : Pounds	Volume : Ft. ³	Weight : Pounds	Volume : Ft. ³	Weight : Pounds	Volume : Ft. ³	Weight : Pounds	Volume : Ft. ³	Weight : Pounds	Volume : Ft. ³	Weight : Pounds	Volume : Ft. ³
5	90.74 (±7.82) ¹	1.36 (±0.13)	136.69 (±7.15)	2.18 (±0.12)	182.64 (±6.68)	2.99 (±0.11)						
6	110.96 (±7.50)	1.72 (±0.13)	177.13 (±6.73)	2.89 (±0.11)	243.29 (±6.43)	4.07 (±0.11)	309.46 (±6.70)	5.24 (±0.11)				
7	134.85 (±7.17)	2.14 (±0.12)	224.91 (±6.46)	3.74 (±0.11)	314.98 (±6.76)	5.34 (±0.11)	405.04 (±7.94)	6.94 (±0.14)				
8	162.42 (±6.86)	2.63 (±0.11)	280.05 (±6.51)	4.72 (±0.11)	397.69 (±7.82)	6.81 (±0.13)	515.32 (±10.14)	8.90 (±0.18)	632.95 (±12.95)	10.98 (±0.22)		
9	193.67 (±6.60)	3.19 (±0.11)	342.55 (±7.04)	5.83 (±0.12)	491.42 (±9.61)	8.47 (±0.16)	640.30 (±13.13)	11.11 (±0.22)	789.18 (±17.01)	13.76 (±0.29)		
10			412.39 (±8.06)	7.07 (±0.14)	596.19 (±12.04)	10.33 (±0.20)	779.99 (±16.77)	13.59 (±0.28)	963.79 (±21.77)	16.86 (±0.37)	1,147.59 (±26.89)	20.12 (±0.46)
11			489.59 (±9.58)	8.44 (±0.16)	711.98 (±14.97)	12.39 (±0.26)	934.38 (±20.96)	16.33 (±0.35)	1,156.78 (±27.15)	20.28 (±0.46)	1,379.18 (±33.43)	24.23 (±0.57)

¹ Numbers in parentheses are confidence limits on the mean.

Basic equations:

$$\text{Bole weight} = 44.79 + 0.1838 (\text{d.b.h.})^2 (\text{bole length})$$

$$\text{S.E.E.} = 0.514 (\text{d.b.h.})^2$$

$$\text{Bole volume} = 0.546 + 0.00326 (\text{d.b.h.})^2 (\text{bole length})$$

$$\text{S.E.E.} = 0.0087 (\text{d.b.h.})^2$$

Table 3.--Sawtimber tree bole weight and bole volume by d.b.h. and bole length (95 percent confidence intervals on the mean)

D.b.h.	Bole length (feet)													
	8		16		24		32		40		48		56	
	Weight : Pounds	Volume : Ft. ³	Weight : Pounds	Volume : Ft. ³	Weight : Pounds	Volume : Ft. ³	Weight : Pounds	Volume : Ft. ³	Weight : Pounds	Volume : Ft. ³	Weight : Pounds	Volume : Ft. ³	Weight : Pounds	Volume : Ft. ³
12	460.9 (±65.5) ¹	8.60 (±1.08)	678.1 (±58.5)	12.57 (±0.96)	895.4 (±52.2)	16.54 (±0.82)	1,112.7 (±46.7)	20.51 (±0.76)	1,329.9 (±42.5)	24.48 (±0.89)				
13	498.6 (±64.3)	9.29 (±1.06)	753.6 (±56.2)	13.95 (±0.92)	1,008.5 (±49.1)	18.61 (±0.81)	1,263.5 (±43.6)	23.27 (±0.72)	1,518.5 (±40.1)	27.93 (±0.66)				
14			835.0 (±53.8)	15.44 (±0.89)	1,130.8 (±46.3)	20.84 (±0.76)	1,426.5 (±41.1)	26.25 (±0.68)	1,722.2 (±39.2)	31.65 (±0.64)	2,017.9 (±41.1)	37.06 (±0.68)		
15			922.5 (±51.4)	17.04 (±0.85)	1,262.0 (±43.7)	23.24 (±0.71)	1,601.5 (±39.5)	29.45 (±0.65)	1,941.0 (±40.3)	35.65 (±0.66)	2,280.5 (±45.6)	41.86 (±0.75)		
16			1,016.1 (±49.0)	18.75 (±0.81)	1,402.3 (±41.4)	25.81 (±0.68)	1,788.6 (±39.3)	32.87 (±0.65)	2,174.9 (±43.6)	39.93 (±0.72)	2,561.1 (±52.5)	46.99 (±0.87)		
17			1,115.7 (±46.7)	20.57 (±0.77)	1,551.7 (±39.9)	28.54 (±0.66)	1,987.8 (±40.8)	36.51 (±0.67)	2,423.8 (±48.9)	44.48 (±0.81)	2,859.8 (±61.4)	52.45 (±1.01)		
18					1,710.1 (±39.2)	31.43 (±0.64)	2,199.0 (±44.0)	40.37 (±0.72)	2,687.8 (±56.1)	49.30 (±0.92)	3,176.7 (±72.1)	58.24 (±1.19)	3,665.5 (±89.8)	67.17 (±1.47)
19					1,877.6 (±39.8)	34.49 (±0.65)	2,422.3 (±48.9)	44.45 (±0.80)	2,967.0 (±65.0)	54.40 (±1.06)	3,511.6 (±84.1)	64.36 (±1.38)	4,056.3 (±104.7)	74.31 (±1.72)
20					2,054.1 (±41.6)	37.72 (±0.68)	2,657.7 (±55.3)	48.75 (±0.91)	3,261.2 (±75.1)	59.78 (±1.23)	3,864.7 (±97.3)	70.81 (±1.60)	4,468.2 (±120.7)	81.84 (±1.98)
21					2,239.7 (±44.7)	41.11 (±0.73)	2,905.1 (±62.9)	53.27 (±1.03)	3,570.5 (±86.3)	65.43 (±1.41)	4,235.9 (±111.7)	77.60 (±1.84)	4,901.3 (±137.9)	89.76 (±2.27)
22					2,434.4 (±49.2)	44.67 (±0.81)	3,164.6 (±71.6)	58.02 (±1.18)	3,894.9 (±98.5)	71.36 (±1.61)	4,625.1 (±126.9)	84.71 (±2.08)	5,355.4 (±156.1)	98.06 (±2.57)
23							3,436.2 (±81.3)	62.98 (±1.34)	4,234.4 (±111.6)	77.57 (±1.83)	5,032.5 (±143.1)	92.17 (±2.37)	5,830.7 (±175.3)	106.74 (±2.88)
24							3,719.9 (±91.9)	68.16 (±1.50)	4,588.9 (±125.5)	84.05 (±2.06)	5,458.0 (±160.2)	99.93 (±2.63)	6,327.1 (±195.5)	115.82 (±3.21)

¹ Numbers in parentheses are confidence interval on the mean.

Basic equations:

$$\text{Bole weight} = 243.59 + 0.1886 (\text{d.b.h.})^2 (\text{bole length})$$

$$\text{S.E.E.} = 0.710 (\text{d.b.h.})^2$$

$$\text{Bole volume} = 4.630 + 0.00345 (\text{d.b.h.})^2 (\text{bole length})$$

$$\text{S.E.E.} = 0.0117 (\text{d.b.h.})^2$$

Steinhilb, H. M., and Sharon A. Winsauer.

1976. Sugar maple: tree and bole weights, volumes, centers of gravity, and logging residue. USDA For. Serv. Res. Pap. NC-132, 7 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

Presents weights, volumes, centers of gravity, and amount of residue for sugar maple trees and boles. Data may be useful to field foresters and equipment design engineers.

OXFORD: 524.2:526.1:372TL:176.1*Acer saccharum*. KEY WORDS: mechanization, skidding, loading, harvesting.

Steinhilb, H. M., and Sharon A. Winsauer.

1976. Sugar maple: tree and bole weights, volumes, centers of gravity, and logging residue. USDA For. Serv. Res. Pap. NC-132, 7 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

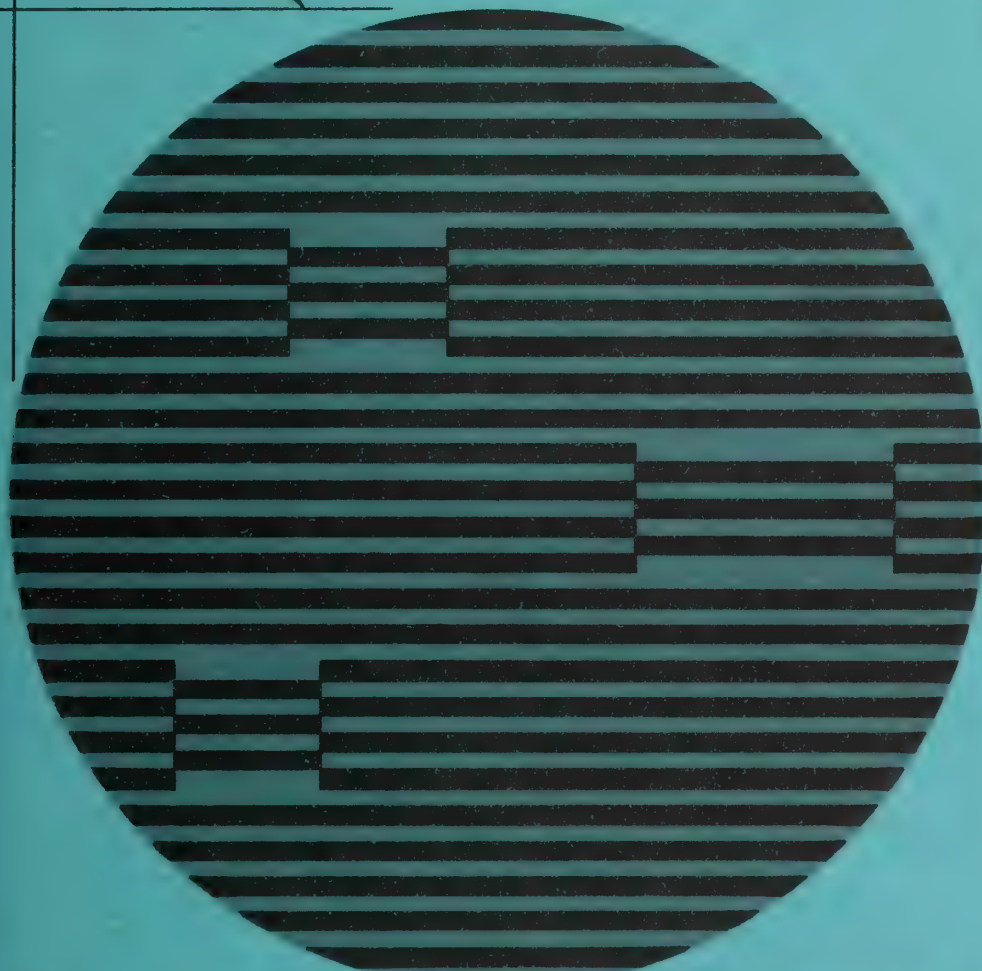
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OXFORD: 524.2:526.1:372TL:176.1*Acer saccharum*. KEY WORDS: mechanization, skidding, loading, harvesting.



crown area

GOVT. DOCUMENTS
DEPOSITORY ITEM



BIOMASS ESTIMATION FOR FIVE SHRUBS FROM NORTHEASTERN MINNESOTA

LEWIS F. OHMANN, DAVID F. GRIGAL
ROBERT B. BRANDER

stem dia.

THE AUTHORS



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CONTENTS

APPLICATION	1
How to Use the Values and Equation	1
DOCUMENTATION	4
Methods	4
Results and Discussion	5
Conclusions	10
Literature Cited	10

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BIOMASS ESTIMATION FOR FIVE SHRUBS FROM NORTHEASTERN MINNESOTA¹

Lewis F. Ohmann, David F. Grigal, and Robert B. Brander

APPLICATION

Land managers and wildlife biologists sometimes need to determine the above-ground biomass of shrubs or the amount of shrub browse available for wildlife.

We have developed a series of values for use in an equation to predict biomass for five shrubs, green alder (*Alnus crispa*), beaked hazel (*Corylus cornuta*), juneberry (*Amelanchier* spp.), willow (*Salix* spp.), and mountain maple (*Acer spicatum*) which are common in northeastern Minnesota. The values and equation can be used to estimate the following: (1) biomass of leaves, (2) biomass of current year's twigs, (3) biomass of stems, and (4) total biomass of the above-ground parts. These biomass estimates could be used to predict available summer browse (leaves) and winter browse (current twigs) for deer and moose.

The values and equation are best used to predict shrub biomass in regenerated clearcuts because the data were obtained from such areas.² But even in nonclearcut areas, predictions from this equation should

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²An exception are the data for mountain maple which were gathered from a mature forest community.

be reasonably accurate so long as the shrub measurements described below fall within the ranges listed in table 1.

HOW TO USE THE VALUES AND EQUATION

To predict any of the four kinds of biomass listed above, you can use any one of four different shrub measurements³:

- (1) Plant height, cm (measure height to nearest 15 cm).
- (2) Crown area, cm² (measure to nearest 15 cm the maximum crown diameter and the diameter 90 degrees to it; compute area of crown using formula $A = \frac{\pi}{4} (d_1) (d_2)$).
- (3) Stem diameter, by 1-cm classes (measure diameter at 15 cm above ground and assign to nearest class; 1-cm class includes 0.5 to 1.4 cm).
- (4) Stem diameter, cm (measure diameter to nearest 0.25 cm, 15 cm above the ground).

Suppose, for example, that you want to know the biomass (in grams) of this year's twigs on a single stem of green alder. To

³Predictions using stem diameter will be slightly more accurate (higher R^2 values) but other measurements, such as plant height, are easier to make and are sufficiently accurate for many applications.

Table 1.--Ranges of shrubs measurements (x's) within which biomass predictions should be accurate

Shrub species	Acceptable range of shrub measurements (x's)			
	Plant height	Crown area	Stem diameter	Stem diameter
	: : Cm	: : Cm ²	: : Cm : classes	: : Cm
Mountain maple	91 - 366	182 - 45,969	0.5 - 3.5	0.6 - 3.2
Green alder	91 - 290	182 - 6,384	.5 - 2.5	.6 - 2.1
Beaked hazel	91 - 213	182 - 5,108	.5 - 2.5	.6 - 2.3
Juneberry	91 - 274	182 - 7,661	.5 - 1.5	.5 - 1.9
Willow	91 - 305	365 - 19,154	.5 - 3.5	.7 - 3.8

predict this you need to take any one of the four measurements listed above, for example number 4--stem diameter. Suppose the stem measured 1.5 cm in diameter. First you check table 1 to see if 1.5 cm falls within the acceptable range (0.6 - 2.1) which it does. Then substitute 1.5 for x in the equation $Y = ax^b$.

"Current year's twigs." You will find that $a = 5.147$ and $b = 1.184$. When we substitute the values for x , a , and b in the equation, we get

$$Y = ax^b$$

$$Y = (5.147)(1.5)^{1.184}$$

Next look up the value of a and b in table 2. First run down the table to the section labeled "USING STEM DIAMETER AS x ", find the "green alder" row, and look for the a and b values under the column headed

Solving for the twig biomass (Y) is most easily done with logarithms.

(1) First find the natural logarithm of 1.5 either from tables or directly on some

Table 2.--Values of a and b for substituting in regression equation $Y = ax^b$ to predict biomass

USING PLANT HEIGHT AS x					
Shrub species		Type of biomass			
		Leaves	Current year's twigs	Stem	Total aboveground parts
Mountain maple	a	2.856E-05	2.639E-03	4.134E-05	1.747E-05
	b	2.599	1.409	2.835	3.047
Green alder	a	2.746E-03	1.739E-03	6.818E-03	1.899E-03
	b	1.738	1.600	1.806	2.120
Beaked hazel	a	--	3.268E-03	2.089E-05	2.791E-04
	b	--	1.373	2.980	2.520
Juneberry	a	6.124E-04	3.041E-04	1.989E-03	2.009E-03
	b	1.998	1.982	2.067	2.096
Willow	a	2.770E-05	1.875E-05	1.011E-05	1.303E-05
	b	2.735	2.571	3.163	3.175
USING CROWN AREA AS x					
Mountain maple	a	0.0115	0.3046	0.0132	0.0071
	b	.8834	.3215	1.064	1.138
Green alder	a	.2869	.2674	1.590	1.373
	b	.5858	.4496	.5354	.5937
Beaked hazel	a	--	.3504	.8201	--
	b	--	.2888	.5770	--
Juneberry	a	.0428	.0819	.7513	.2786
	b	.7849	.6072	.6250	.7641
Willow	a	.0084	.0047	.0157	.0115
	b	1.025	.9590	1.109	1.166
USING STEM CLASS AS x					
Mountain maple	a	12.69	3.581	47.88	64.38
	b	1.818	0.6826	2.486	2.320
Green alder	a	19.78	5.788	56.96	82.35
	b	.6824	.6727	1.052	1.038
Beaked hazel	a	--	2.486	40.10	66.16
	b	--	.3646	0.5878	0.6363
Juneberry	a	15.40	6.303	64.14	82.93
	b	.7386	1.128	1.204	0.9507
Willow	a	28.39	6.577	56.77	99.96
	b	1.362	1.602	2.266	1.936
USING STEM DIAMETER AS x					
Mountain maple	a	11.13	3.244	40.94	52.09
	b	2.123	.9149	2.781	2.724
Green alder	a	13.97	5.147	43.94	55.45
	b	1.682	1.184	2.214	2.409
Beaked hazel	a	--	2.371	38.57	54.10
	b	--	.7265	1.582	1.229
Juneberry	a	13.34	5.923	50.63	64.18
	b	1.547	1.685	2.547	2.322
Willow	a	21.59	5.823	56.09	87.79
	b	1.686	1.789	2.208	1.981

of the new electronic calculators.
) Multiply the log of 1.5 (0.4055) by b and find the antilog of that product. The product is 0.4801 and the antilog is 1.616.

) Then multiply the antilog by a (5.147×1.616) to obtain the value of Y , current year's twig biomass, 8.32 g. The steps are as follows:

) $\log 1.5 = 0.4055$, substituting in the above equation we get

) $Y = (5.147)(\text{antilog of } (0.4055)(1.184))$
 $= (5.147)(\text{antilog of } 0.4801)$

$$\begin{aligned}(3) &= (5.147)(1.616) \\ &= 8.32 \text{ grams}\end{aligned}$$

This value will be the same for each green alder stem with a diameter of 1.5 cm so that the calculation needs to be made only once for that diameter of green alder stem.

If you wish to determine biomass or browse biomass per acre or other unit of area, a sampling scheme using units such as milacre plots can be devised to determine number and size of shrubs. Multiplying the mass (Y) from the above equation by the number of shrub stems of each size and species on a certain area would yield the total mass of the stems of the species.

DOCUMENTATION

Indirect estimation of biomass of the shrub component of plant communities is becoming increasingly important in forest ecology and wildlife habitat research (McKell *et al.* 1972). Equations have been developed for estimating total biomass or biomass of some parts of boreal forest shrubs. Many of these equations either are based on dependent and independent variables that are measured in a variety of ways, or are designed to predict some aspect of biomass that is uniquely defined, or both.

Peek (1970) evaluated the relations of plant height, canopy cover, shrub volume, and number of twigs to twig biomass production in beaked hazel (*Corylus cornuta* Marsh.) and willow (*Salix discolor* Muhl.). For hazel, the independent variable, canopy cover, was defined as the cross sectional area of a clone of stems rather than the area of individual plant crowns. The dependent variable, twig biomass, was leaves and current year's twig growth. Tappeiner and John (1973) presented prediction equations for estimating total biomass and that of three components (leaves, aerial stems, and underground parts) of hazel per unit land area. Two of the independent variables used in their equations were shrub basal area/M², derived from stem diameter at 30 cm above ground, and number of stems/ha.

Lyon (1968) related twig production in juneberry (*Amelanchier* Medic.) to crown volume. The dependent variable in the equations was current year's twig growth (exclusive of leaves) of individual plants. Shafer (1963) reported a twig-count method to determine weight per unit area of available and utilized winter browse, based on the average diameter at the point of browsing for an unbiased sample of twigs of several species. Telfer (1969) presented prediction equations for twig weights based on twig diameters at point of browsing for each of 22 species of plants.

We recently described changes in biomass from mid-June through early December for five shrub species from northeastern Minnesota (Ohmann *et al.* in press). In the present report we further examine a portion of those data to develop prediction equations for total aboveground biomass and for biomass of certain parts of shrubs. Some

of the relations we examine are between commonly measured parameters in forest ecology and wildlife habitat studies thus the equations we present could also be used to predict biomass using data from past habitat studies in northeastern Minnesota.

METHODS

Data Collection

Five shrubs, mountain maple (*Acer spicatum* Lam.), green alder (*Alnus crispa* (Ait.) Pursh.), juneberry (*Amelanchier* spp. Medic.), beaked hazel (*Corylus cornuta* Marsh.), and willow (*Salix* spp.L.), were sampled at about 2-week intervals from 15 June through 8 December 1971 (Ohmann *et al.* in press). Nine stems of each shrub were cut at ground level and randomly collected on each of the 13 sample dates (12 for willow). Even-aged stems of all shrubs except maple were collected from a 1-hectare clear-cut having homogenous soils and topography. Mountain maple was collected from a similar area in a nearby uncut forest and was also nearly even-aged (Ohmann *et al.* in press).

For each stem we recorded: height above ground (plant height), length of crown (crown depth), maximum crown diameter and diameter at right angles to it (to compute crown area), two measures of stem diameter at 15 cm above ground (diameter class and stem diameter), stem diameter at crown base (base diameter), stem length, and number of annual rings at the stem base. Plant height, crown depth, and diameter used to compute crown area were measured to the nearest 15 cm; diameter class to the nearest centimeter; stem diameter and base diameter to the nearest 0.25 cm; and stem length to the nearest 3 cm. All the above parameters are hereafter referred to as predictor variables.

Leaves, current year's twig growth, last year's twig growth, stem, fruits, and buds were all separated. Each component was bagged, dried at 75° for a minimum of 48 hours, and its mass was determined to the nearest 0.01 gram. The five biomass variables analyzed were leaves, this year's twigs, last year's twigs, stem (excluding fruits and buds), and total aboveground mass (including fruits and buds).

We sampled stems throughout the growing season and into the early winter dormant period. Therefore, phenological development differed over the entire sample period. Only data collected on five sample dates (7 July through 1 September when mature leaves were present) were used to examine the relations involving leaf biomass and total aboveground biomass. Data from 10 collection dates (21 July through December) were used to examine relations involving this year's twig, last year's twig, and stem biomass. This was the period during which twig elongation was essentially complete (Ohmann *et al.* in press).

Data Analysis

We first analyzed five biomass variables and eight predictor variables for each of the five species. To determine which combinations of single variables would yield useful prediction equations, and to gain insight as to the appropriate form of the equation, we screened all possible single combinations using four functional relations (Crow 1971). A regression was calculated for each combination of biomass and predictor variable for each species using four equations in their linearized form:

$$\text{Linear} \quad Y = A + BX \quad (1)$$

$$\begin{aligned} \text{Exponential} \quad Y &= Ae^{BX} \\ \ln Y &= \ln A + BX \end{aligned} \quad (2)$$

$$\begin{aligned} \text{Allometric} \quad Y &= AX^B \\ \ln Y &= \ln A + B \ln X \end{aligned} \quad (3)$$

$$\begin{aligned} \text{Hyperbolic} \quad Y &= X/(A + BX) \\ 1/Y &= B + A(1/X) \end{aligned} \quad (4)$$

To assess the resulting 800 regressions, we first compared the results from each of the four models. The index of fit, R^2 , is a poor criterion for comparing and choosing between regression models with different dependent variables. Hafley (1969) and Furnival (1961) suggest the use of a maximum likelihood function as an alternative means of comparing models. Because we were more interested in selecting a single model for suitable predictions based on the many possible relations between predictor and biomass variables for all five

species, rather than the best model for each specific relation, we used the simpler measure of relative error, e , $(\sum y \cdot x / \bar{y})$ (Whittaker and Woodwell 1968) to evaluate the four functions.

The relative error estimate is analogous to the coefficient of variation, thus a value of 0.10 for e suggests an expected error for a given estimate of Y of ± 10 percent at $\bar{X}$ (Whittaker and Woodwell 1968). Relative error has another advantage over the traditional index of fit, R^2 ; it is not sensitive to scale, so it is a suitable criterion for comparing results based on data such as these (table 1) that vary considerably in size. We examined the relative error associated with regressions of all combinations of a predictor and a biomass variable, using each of the four functions derived from the linearized form. However, we calculated e after transforming the variables back to their original form. To further evaluate the models we plotted the residual sums of squares for a number of regressions to determine if there were significant trends away from the best-fit regression line.

After the functional form of the equation was chosen, we selected predictor and biomass variables that either showed the best relation based on relative errors, or that were of particular interest to our study. The data were then re-analyzed using an iterative nonlinear least squares technique to derive the prediction equations.

RESULTS AND DISCUSSION

Basic Data

Our equations are most suitable as predictors for other data sets when the size ranges of those sets fall within the size ranges of our variables (table 3).

Crown area varied (as measured by standard deviation) more than most of the other predictor variables, and also showed the greatest difference within species when data from 5 sampling dates were compared to those from 10 dates (table 3). The variation in crown area--as well as that in the other variables--results in part from biomass changes in these shrubs over the growing season (Ohmann *et al.* in press). Even though these changes are somewhat obscured

Table 3.--Means, standard deviations, ranges, and number of stems collected for independent and dependent variables, for five shrub species

Species	Stems collected	Independent variables				Stem diameter class ¹				Stem diameter				Leaf biomass				Current year's twig biomass				Stem biomass				Total aboveground biomass			
		Plant height ² (SD)	Mean (SD)	Crown area (cm ²)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range		
Mountain maple	45	186 (66)	91-366	7,321 (9,086)	182-45,969	1.3 (0.77)	0.5-3.5	1.4 (0.62)	0.7-3.2	28 (33)	3-153	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---		
	90	185 (67)	91-366	5,892 (7,387)	182-45,969	1.4 (0.66)	0.5-3.5	1.4 (0.57)	0.6-3.2	---	---	---	---	---	---	---	---	4.3 (3.86)	0.2-22.6	148 (205)	9-1,236	---	---	---	---	---	---		
	45	166 (42)	91-259	1,658 (1,406)	365-6,384	1.1 (0.58)	0.5-2.5	1.2 (0.33)	0.7-2.1	21 (13)	5-54	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---			
Green alder	45	166 (42)	91-259	1,658 (1,406)	365-6,384	1.1 (0.58)	0.5-2.5	1.2 (0.33)	0.7-2.1	21 (13)	5-54	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---			
	90	162 (39)	91-290	1,336 (1,189)	182-6,384	1.2 (0.52)	0.5-2.5	1.2 (0.31)	0.6-2.1	---	---	---	---	---	---	---	---	6.2 (4.13)	0.2-17.2	69 (46)	9-260	---	---	---	---	---	---		
	45	115 (27)	91-213	1,022 (1,107)	182-5,108	0.7 (0.44)	0.5-2.5	0.9 (0.30)	0.6-2.3	11 (9)	2-50	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---			
Beaked hazel	90	113 (23)	91-213	681 (681)	182-5,108	0.8 (0.47)	0.5-2.5	0.9 (0.24)	0.6-2.3	---	---	---	---	---	---	---	---	2.2 (1.32)	0.4-8.6	33 (42)	7-300	---	---	---	---	---	---		
	45	151 (41)	91-259	1,837 (1,536)	182-7,661	1.0 (0.51)	0.5-1.5	1.1 (0.31)	0.5-1.9	15 (11)	3-54	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---			
	90	153 (47)	91-274	1,732 (1,732)	182-7,661	1.1 (0.50)	0.5-1.5	1.1 (0.32)	0.5-1.9	---	---	---	---	---	---	---	---	7.0 (6.24)	0.1-34.6	72 (57)	6-272	---	---	---	---	---	---		
Juneberry	36	165 (54)	91-305	3,821 (4,443)	547-19,154	1.2 (0.76)	0.5-3.5	1.4 (0.67)	0.8-3.8	40 (59)	4-307	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---			
	90	171 (47)	91-305	3,577 (3,490)	365-19,154	1.4 (0.58)	0.5-3.5	1.5 (0.53)	0.7-3.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---			
	90	171 (47)	91-305	3,577 (3,490)	365-19,154	1.4 (0.58)	0.5-3.5	1.5 (0.53)	0.7-3.8	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---			

¹Minimum height sampled 91.4 cm.

²Minimum class 0.5 cm.

³Collected over five sample periods.

⁴Collected over 10 sample periods.

⁵Based on only 44 stems.

⁶Based on only 89 stems.

when the data are "blocked" over time periods in the analyses, they probably contribute to the variability (high relative and standard errors) of the resulting equations. On the other hand, most extensive surveys of vegetation or browse require sampling over much of the growing season (or winter). So the extent to which seasonal change in biomass is included in our analyses (because of the long sampling period) may make our equations more applicable to such extensive vegetation surveys.

Selection of Equation Form

The relative errors associated with the 800 linearized equations indicated that the linear and allometric forms were superior to the exponential and hyperbolic forms for describing relations between predictor and biomass variables. For each species we ranked the four functions (1 through 4, lowest to highest) according to relative error associated with each predictor-biomass regression. These rankings were averaged for all species--a total of 200 ranks for each function. The resulting average ranks in ascending order were: linear (1.2), allometric (2.2), exponential (2.7), hyperbolic (3.9).

We expected the linear function to perform better than the other functions in describing some relations (e.g., that between last year's twig biomass and number of annual rings), but we did not expect the linear function to give a consistently small (in terms of relative error) but better description of the relations for almost all variables. We selected the allometric function to derive the prediction equations because: (1) its relative errors were very close to those of the linear function; (2) it is widely accepted for estimating biomass where a curvilinear trend is expected as the predictor variable increases.⁴

Selection of Predictor Variables

Stem diameter was the best predictor of biomass. For each species the eight predictor variables were ranked one through eight from the lowest to highest relative error associated with each combination of variables. The rank of each predictor variable was then averaged for all species.

⁴The linear function could also have been used for further analyses (Ovington et al. 1967, Post 1970).

the resulting average rank in ascending order was stem diameter (3.2), plant height (4.4), stem length (3.6), crown area (3.7), base diameter (3.7), crown depth (5.0), diameter class (6.1), and annual rings (7.6). The rankings were very similar for mountain maple, willow, and green alder; the ranking for juneberry was more similar to those three species than to beaked hazel which had much different rankings. If hazel is excluded from the calculations, average rank of relative error becomes stem diameter (2.9), base diameter (3.0), crown area (3.3), plant height (3.7), stem length (4.1), crown depth (5.2), diameter class (6.3), and annual rings (7.6).

Some of the predictor variables are closely related--such as those in each of the following groups: base diameter, stem diameter, and diameter class; stem length and plant height; and crown area and crown depth. We decided to continue the analyses with the diameter measures taken at 15 cm above ground because they could be applied more consistently in the field. Plant height rather than stem length was retained because it, too, could be more readily measured in the field. Crown area was retained because Peek (1970) suggested its use as an direct measure of biomass for beaked hazel and willow. Finally, diameter class had been used in recent vegetation surveys in the area (Ohmann and Ream 1971, Ohmann *et al.* 1973) and was of particular interest to us, so it was retained although its relative error was higher than in most of the other predictor variables. Crown depth and annual ring count were eliminated from further analysis.

Selection of Biomass Variables

Of the five biomass variables, stem biomass was best predicted by the linearized equations using the allometric function. For each species, each combination of biomass-predictor variable was ranked one through five, lowest to highest, according to its relative error. The ranks for all equations containing a given biomass variable were averaged for all species. The resulting average rank was stem (2.4), this year's twig (2.8), leaf (2.9), total above ground (3.0), and last year's twig biomass (4.0). The ranking of best-estimated biomass variables were most similar for juneberry and green alder, followed by willow and mountain maple. All of these species are more similar to one another than they

were to beaked hazel, which had a different average ranking of errors. If beaked hazel is excluded from the average, the order becomes stem (2.0), leaf (2.4), total above ground (2.5), this year's twig (3.2), and last year's twig biomass (4.4).

Because the average ranking of relative error for last year's twig biomass was high in comparison to the other variables, and because it seemed a less important component to consider separately, it was dropped from further analysis.

After screening we retained four biomass variables (leaf, this year's twig, stem, and total aboveground biomass) and four predictor variables (plant height, crown area, diameter class, and stem diameter) for further analysis.

Prediction Equations

All of the prediction equations, except a few for hazel, accounted for statistically significant (0.05 level) amounts of variation in the dependent variable. The equation parameters along with their associated R^2 's and standard errors of estimate are presented in table 4. The index of fit, R^2 , is appropriate for use in comparing data for the same dependent variable in table 4. A correction factor for bias due to logarithmic transformation of the data was unnecessary because a nonlinear technique on untransformed data was used to determine the parameters for each equation.

Biomass Variable Relations

Leaf biomass of mountain maple, juneberry, and willow was most closely related to crown area (in terms of highest R^2 and lowest $Sy.x$), while leaf biomass of alder was better related to stem diameter than to crown area. None of the relations between leaf biomass and predictor variables was statistically significant for hazel. The relations between leaf biomass and the predictor variables, measured by R^2 , were highest for maple, while those for the other three species were similar and considerably lower (table 4).

Biomass of this year's twig was most closely related to plant height in all species except willow, where it was better related to crown area (table 4). For maple, alder, and hazel, crown area was the second-best predictor, and for juneberry

Table 4.--Regressions for estimation of biomass of shrubs from north-eastern Minnesota (allometric relation $Y = ax^b$)

REGRESSIONS ON PLANT HEIGHT (cm)						
Item		Mountain maple	Green alder	Beaked hazel	Juneberry	Willow
Leaf biomass (g)	a	2.856E-05	2.746E-03	---	6.124E-04	2.770E-05
	b	2.599	1.738		1.998	2.735
	R ²	0.70	0.49		0.54	0.43
	S y.x	18.4	9.4		7.7	44.6
This year's twig biomass (g)	a	2.639E-03	1.793E-03	3.268E-03	3.041E-04	1.875E-05
	b	1.409	1.600	1.373	1.982	2.571
	R ²	0.33	0.40	0.23	0.55	0.31
	S y.x	3.2	3.2	1.2	4.2	12.4
Stem biomass (g)	a	4.134E-05	6.818E-03	2.089E-05	1.989E-03	1.011E-05
	b	2.835	1.806	2.980	2.067	3.163
	R ²	0.67	0.46	0.37	0.67	0.58
	S y.x	117.8	33.8	33.7	32.9	106.7
Total above- ground biomass (g)	a	1.747E-05	1.899E-03	2.791E-04	2.009E-03	1.303E-05
	b	3.047	2.120	2.520	2.096	3.175
	R ²	0.65	0.53	0.36	0.52	0.68
	S y.x	170.3	52.1	51.7	45.6	154.9
REGRESSIONS ON CROWN AREA (cm ²)						
Leaf biomass (g)	a	0.0115	0.2869	---	0.0428	0.0084
	b	0.8834	0.5858		0.7849	1.025
	R ²	0.86	0.58		0.66	0.66
	S y.x	12.3	8.6		6.7	34.8
This year's twig biomass (g)	a	0.3046	0.2674	0.3504	0.0819	0.0047
	b	0.3215	0.4496	0.2888	0.6072	0.9590
	R ²	0.22	0.35	0.11	0.35	0.56
	S y.x	3.4	3.4	1.2	5.1	10.0
Stem biomass (g)	a	0.0132	1.590	0.8201	0.7513	0.0157
	b	1.064	0.5354	0.5770	0.6250	1.109
	R ²	0.82	0.48	0.13	0.51	0.84
	S y.x	86.2	33.2	39.6	40.4	65.2
Total above- ground biomass (g)	a	0.0071	1.373	---	0.2786	0.0115
	b	1.138	0.5937		0.7641	1.166
	R ²	0.89	0.48		0.61	0.91
	S y.x	96.9	54.8		40.9	84.6
REGRESSIONS ON STEM CLASS (cm)						
Leaf biomass (g)	a	12.69	19.78	---	15.40	28.39
	b	1.818	0.6824		0.7386	1.362
	R ²	0.64	0.34		0.27	0.54
	S y.x	20.1	10.7		9.8	40.3
This year's twig biomass (g)	a	3.581	5.788	2.486	6.303	6.577
	b	0.6826	0.6727	0.3646	1.128	1.602
	R ²	0.17	0.28	0.11	0.32	0.26
	S y.x	3.5	3.5	1.2	5.2	12.8
Stem biomass (g)	a	47.88	56.96	40.10	64.14	56.77
	b	2.486	1.052	0.5878	1.204	2.266
	R ²	0.82	0.40	0.07	0.44	0.67
	S y.x	87.3	35.8	40.9	43.0	94.4
Total above- ground biomass (g)	a	64.38	82.35	66.16	82.93	99.96
	b	2.320	1.038	0.6363	0.9507	1.936
	R ²	0.79	0.56	0.09	0.38	0.67
	S y.x	132.0	50.3	61.6	51.6	158.1
REGRESSIONS ON STEM DIAMETER (cm)						
Leaf biomass (g)	a	11.13	13.97	---	13.34	21.59
	b	2.123	1.682		1.547	1.686
	R ²	0.80	0.63		0.47	0.54
	S y.x	15.0	8.1		8.7	40.3
This year's twig biomass (g)	a	3.244	5.147	2.371	5.923	5.823
	b	0.9149	1.184	0.7265	1.685	1.789
	R ²	0.22	0.29	0.11	0.37	0.48
	S y.x	3.4	3.5	1.2	5.0	10.8
Stem biomass (g)	a	40.94	43.94	38.57	50.63	56.09
	b	2.781	2.214	1.582	2.547	2.208
	R ²	0.93	0.87	0.20	0.90	0.92
	S y.x	53.4	16.7	38.1	17.9	47.9
Total above- ground biomass (g)	a	52.09	55.45	54.10	64.18	87.79
	b	2.724	2.409	1.229	2.322	1.981
	R ²	0.92	0.94	0.13	0.83	0.87
	S y.x	80.0	18.3	61.1	27.0	99.3

willow, stem diameter was related second best (table 4). Although relations were statistically significant, none of the R^2 's was very high; for example, R^2 's for regressions predicting current twig biomass were above 0.50 only for willow and junewillow.

Stem biomass was most closely related to stem diameter in all species except willow, where it was most closely related to plant height. However, for hazel, this R^2 was lower than those related to stem diameter for the other species (table 4). The R^2 's for the stem biomass-stem diameter regressions (with the exception of hazel) were high and very similar, ranging from 0.77 to 0.93. Crown area also appeared to be closely related to stem biomass in maple and willow.

Total aboveground biomass was most closely related to stem diameter in maple, junewillow, and junewillow, with R^2 's from 0.83 to 0.94. In willow the R^2 for prediction of total biomass based on crown area was slightly higher than that based on stem diameter ($R^2 = 0.91$ versus 0.87). Crown area also related well to total biomass in maple ($R^2 = 0.89$). In hazel, R^2 's relating total biomass to all predictor variables were low (largest was 0.36 for relation with plant height), and the relation of crown area to total biomass was not statistically significant.

Performance of Predictor Variables

Plant height.--Plant height is easily measured in the field, especially when it is recorded to the nearest 15 cm as in this study. Unfortunately, measurements by large measurement intervals influence the resulting regression estimates, their standard errors, and R^2 's. However, the relative errors associated with plant height in the linearized regressions were lower than those for stem length, presumably a more precise measure of the same parameter. We suspect that if plant height had been measured more precisely, it would have performed more nearly like stem diameter as a predictor variable. A combination of a more precise measure of plant height and of stem diameter as predictor variables in a multiple regression would probably account for much of the variation in shrub biomass, just as it does in the prediction of biomass in tree species.

In spite of the possible effect of imprecise measurement, an R^2 of 0.70 was obtained for the regression of leaf biomass

on plant height in maple, and except for twig biomass, most of the R^2 's for this predictor were in the 0.50 to 0.60 range.

Peek (1970) reported correlations coefficients of $r = 0.88$ and $r = 0.76$ for allometric regressions of twig weight (including both wood and leaf material) on plant height in willow and hazel. Because of a difference in twig definition, direct comparison is impossible. We found equivalent correlations of $r = 0.66$ and $r = 0.56$ in willow; and $r = 0.21$ and $r = 0.48$ in hazel for leaf and twig biomass regressions on plant height, respectively. In addition to the definition problem, there are methodological differences in the two studies that might account for the differences. Our material was sampled over time and consisted of all twig and leaf material present on each plant. Peek collected subsamples of twigs only once.

Crown area.--As expected, crown area performed well in comparison to the other predictor variables in accounting for leaf biomass. It also related well to total aboveground biomass. The highest R^2 's for this variable occurred in regressions of total biomass on crown area ($R^2 = 0.89$ in maple and $R^2 = 0.91$ in willow), but total biomass was accounted for better in most cases by stem diameter. Leaf relations with crown area resulted in R^2 's ranging from 0.58 to 0.86. Except for leaf equations in hazel and all those related to twig biomass, most R^2 's involving crown area were above 0.50.

Peek (1970) also used crown area to predict twig weight (again including wood and leaf material). Correlations from our study for leaf ($r = 0.81$) and twig ($r = 0.75$) are lower than Peek's ($r = 0.96$) for willow. Our values for hazel ($r = 0.22$ for leaf and $r = 0.33$ for twig) are much lower than those reported by Peek ($r = 0.93$). The difference in this case is probably due to the definition of canopy area. Peek used the crown area of clones of stems while we used the canopy area of individual stems as the predictor variable.

Based on Lyon's (1968) finding that crown volume in junewillow is a more accurate predictor of twig production than is crown surface area, a multiple regression of crown depth and area might be appropriate for estimating twig biomass.

Stem class.--Like plant height, stem class suffers from lack of precision that influences the resulting estimates, their standard errors, and R^2 's. In this study, stem diameter differed from stem class only in that it was a more precise measure (nearest 0.25 cm versus nearest cm). The standard errors of estimate for regressions using stem class as a predictor variable are always larger than those which use stem diameter (the standard errors of twig biomass estimates based on stem class average 1.05 greater than those using stem diameter; leaf 1.20 greater; stem 1.82 greater; and total 1.78 greater). Thus, although stem class is a convenient field measure, it should be used only if a more precise measure of diameter is not feasible. Where twig biomass estimation is of special interest, plant height is a better field predictor.

Stem diameter.--For leaf, stem, and total aboveground biomass estimation, this variable was a better predictor than the other variables, and for estimation of twig biomass it ranked second for three of the species. The highest R^2 associated with this predictor was 0.94 for the relation to total biomass in alder, but R^2 's in the low 90's and high 80's were common for both total and stem biomass estimates. The R^2 's tended to be lower for leaf and twig biomass estimates.

Tappeiner and John (1973) presented allometric regression equations for hazel using basal area based on stem diameter measured at 30 cm above ground. They found both aerial stem biomass (R^2 of 0.93) and leaf biomass (0.97) were related to basal area. Both the dependent and independent variables in their case were defined per unit land area, in contrast to variables based on individual stems in this study. Use of basal area for prediction of individual stem biomass was not examined here, but in the allometric form basal area and stem diameter differences only affect the size of the parameters and not the relation, so the results should have been similar.

In this study hazel stem biomass was related to stem diameter with an R^2 of 0.20, and to leaf biomass with a statistically nonsignificant R^2 of 0.03. We have no explanation for these widely varying results between our study and Tappeiner and John (1973). We presumed that the growth form and clonal nature of hazel make it

difficult to predict biomass of individual plants or plant components from parameters measured on individual stems. Apparently biomass estimates in hazel should be tied to area or clonal measures.

CONCLUSIONS

(1) Except for hazel, a random sample of weights of individual stems or stem components combined with rather simple, rapid, field measurements of heights, crowns, or stems will provide relatively good biomass estimates for single plants. These estimates can then be related to density or to other shrub or community characteristics. In the case of hazel, however, estimates should be based on either clones or unit area.

(2) At least three (plant height, crown area, stem diameter) of the four predictor variables used here are useful for predicting either total aboveground biomass or biomass of stem components. Also, for four (mountain maple, green alder, junberry, and willow) of the five species the various relations were similar enough that a single overall equation based on those four species might serve to estimate shrub biomass for purposes such as reconnaissance studies. The fact that the R^2 's of many of the final prediction equations are lower than might be expected may be partly because biomass changes were incorporated into the analysis by sampling over time.

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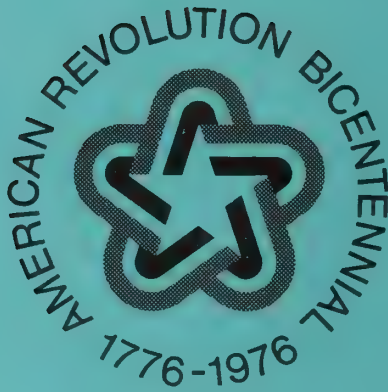
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Hardwoods Planted In Old Fields Favored By Prior Tree Cover

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CONTENTS

The Studies	1
Results	3
Discussion and Conclusions	11
Application of Results	14
Literature Cited	15

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HARDWOODS PLANTED IN OLD FIELDS

FAVORED BY PRIOR TREE COVER

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Large areas of marginal farm land located in hilly parts of the Midwest have been abandoned since the turn of the century. Several species of pine grow rapidly when planted on such land (Limstrom 1963), but successful plantings of hardwoods are rare, even where deep, well drained soils are apparently well suited for hardwoods. Nevertheless, hardwoods such as yellow-poplar (*Liriodendron tulipifera* L.) sometimes naturally seed into young pine plantations on the better soils. These volunteer hardwoods commonly grow faster than pines on the better sites even though growth would have been poor if the hardwoods had been planted in the grassy cover present a few years following land abandonment.

We studied an abandoned field in southern Indiana to determine whether planted hardwood growth differed according to vegetation. We also wanted to determine if these growth differences were associated with differences in physical, chemical, and biological soil conditions. Our results reveal that growth of planted hardwoods is strikingly different for areas that had supported some kind of tree cover since abandonment. These growth differences were associated with foliar nitrogen, and with several physical, chemical, and biological soil factors. We attribute the striking growth differences to the combined effect of soil conditions that have been improved by many years of tree cover present on abandoned agricultural land.

We have already published several papers describing the pot culture and endomycorrhizal results of our studies. In this paper we give 16-year results from field-planted hardwoods, and also we relate our field results to our previously published results. In addition, we attempt to relate our research to research elsewhere so as to, hopefully, give some overall perspective and interpretation to the complex problem of hardwood tree growth on abandoned agricultural land.

THE STUDIES

The Study Area

Our study area is a large field abandoned in the mid-1930's located on the Paoli Experimental Forest within the Hoosier National Forest in Orange County, Indiana. When we began our studies in 1960, the field was bordered by a second-growth hardwood forest. The outer portions of the field were unevenly stocked with volunteer hardwood trees and shrubs; the inner portion was in the grassy, nonstocked stage of natural old-field succession. In 1937 short-leaf pine (*Pinus echinata* Mill.) had been planted on part of the nonstocked area, and black locust (*Robinia pseudoacacia* L.) had been planted on a few areas that were severely eroded.

Hardwoods were planted in 1960 on four areas having different vegetation (table 1): (1) a nonstocked area, and areas clearcut from (2) a fully stocked stand of volunteer trees and shrubs, (3) a 23-year-old short-leaf pine plantation, and (4) a 23-year-old black locust plantation. Soil conditions were studied in these four areas and also in the hardwood forest and in an area half stocked with volunteer trees and shrubs. Most of the study areas are within about 550 feet of each other and generally represent a transect extending from the nonstocked area to the hardwood forest. The locust area is about 790 feet from the other study areas.

The study plots are on a broad, gently rolling ridge; slopes range from 4 to 10 percent, and aspect is south and southeast. The soils are Zanesville and Tilsit silt loams (fine-silty, mixed, mesic Typic Fragiudalfs, and Typic Fragiudults, respectively) that have developed from loess deposits overlying residual sandstone and shale. These soils are similar except for depth to an underlying fragipan: the Tilsit fragipan begins at about 20 inches causing

Table 1.--Description and plant composition of the six study areas in 1960

Area	Tree age : Years	Stand basal area : Ft ² /acre	Species composition
Hardwood forest	60 to 80	143	Oaks (<i>Quercus</i> spp.) Hickories (<i>Carya</i> spp.) Sugar maple (<i>Acer saccharum</i> Marsh.) White ash (<i>Fraxinus americana</i> L.)
Nonstocked area	--	--	Broomsedge (<i>Andropogon virginicus</i> L.) Poverty oatgrass (<i>Danthonia spicata</i> (L.) Beauv.) Goldenrod (<i>Solidago</i> spp.)
Half-stocked area	0 to 30	41	Sassafras (<i>Sassafras albidum</i> (Nutt.) Nees) Persimmon (<i>Diospyros virginiana</i> L.) Elm (<i>Ulmus americana</i> L.)
Fully stocked area	0 to 30	88	Same as half-stocked field
Shortleaf pine plantation	23	137	Shortleaf pine (<i>Pinus echinata</i> Mill.)
Black locust plantation	23	68	Black locust (<i>Robinia pseudoacacia</i> L.)

some restrictions in internal drainage; the Zanesville fragipan begins at about 33 inches, resulting in somewhat better internal drainage (table 2).

Field Plantings

In 1960, one plot was established on each of the four areas. Each plot was 50

Table 2.--Soil descriptions for the six study areas

Area	Soil : type	Soil : horizon	Depth : Inches	Sand : Percent	Silt : Percent	Clay : Percent	pH	p ¹ : l/m	K ¹ : l/m
Natural hardwood forest	Zanesville silt loam integrate to Wellston	A1	0-3	10	65	25	5.9	2	83
		A2	3-6	12	65	23	5.8	2	75
		B1	6-8						
		B21	8-16	12	61	27			
		B22	16-34	17	51	32			
Nonstocked area	Tilsit silt loam	² B23x	34+						
		Ap	0-3	10	63	27	5.8	2	46
		Ap	3-6				5.8	2	29
		B1	6-14	8	54	38			
		B21	14-21						
Half-stocked area	Tilsit silty clay loam intergrade to Zanesville	² B22x	21-26	14	52	34			
		Ap	0-3	11	61	28	6.0	2	52
		Ap	3-5				5.8	2	37
		B1	5-13	11	57	32			
		B21	13-27	13	55	32			
Fully stocked area	Tilsit silt loam	² B22x	27-47	11	53	36			
		Ap	0-3	11	63	26	6.0	2	89
		Ap	3-6				5.8	2	60
		B1	6-11	10	58	32			
		B21	11-20	15	52	33			
Shortleaf pine plantation	Zanesville silt loam	² B22x	20-42	11	56	33			
		A1	0-2				6.6	2	66
		Ap	2-4	12	62	26	6.2	2	37
		B1	4-9						
		B21	9-14	10	60	30			
Black locust plantation	Zanesville silty clay loam (severely eroded) intergrade to Wellston	B22	14-33	9	54	37			
		² B23x	33-42						
		B1	0-3	12	59	29	5.6	5	83
		B1	3-4.5				5.3	2	32
		B21	4.5-9						
		B22	9-15	10	52	38			
		B23	15-22	12	54	34			
		² B24x	22-32						

¹Tests for "readily available" P and K were made by the Purdue University Soil Testing Laboratory using 0.75 N HCl--results are expressed on the elemental basis.

²Fragipan horizon is denoted by "x".

by 100 feet surrounded by a 35-foot isolation strip. All trees and shrubs were removed and stumps were treated with herbicide to reduce sprouting. On each plot we planted 50 1-0 seedlings each of red oak (*Quercus rubra* L.), black walnut (*Juglans nigra* L.), sweetgum (*Liquidambar styraciflua* L.), and yellow-poplar. Seedlings were planted in 5 randomly assigned rows of 10 seedlings each and spacing was 5 by 5 feet. Planted trees were released from competing brush and sprouts as necessary.

At the time of planting, broomsedge and poverty grass covered the nonstocked area. Little herbaceous growth developed on the other three areas in the first growing season following clearing and planting, but in subsequent years dense growth developed on plots in the fully stocked and shortleaf pine areas; herbaceous growth was especially dense in the black locust area.

Foliar samples were collected at 5, 10, and 16 years and were analyzed for nitrogen, phosphorus, and potassium.¹

Soil Measurements

Soil profiles were described in 1962, and composite soil samples were collected for determining texture (Bouyoucos 1951), organic content (Walkley 1947), pH, and "readily available" phosphorus and potassium. For each area 5 to 15 undisturbed 21.2-in.³ soil cores collected at 1-to-4-inch, and the 9-to-12-inch depths for determining bulk density and noncapillary pore volume (Leamer and Shaw 1941).

Pot Culture Studies

To compare growth of field planted yellow-poplar seedlings with growth of seedlings grown in the laboratory we collected three undisturbed, 0.8-gallon soil cores

¹On each area several healthy leaves were collected from the upper crown of at least 10 sample trees in late August; leaves were dried at 68° C for 24 hours, petioles were removed, and leaves were ground in a Wiley Mill. Foliar analyses of 5-year samples were made by the Iowa State Soil Testing Laboratory, 10-year samples were analyzed by the Ohio Agricultural Research and Development Center, and 16-year samples were done by the University of Minnesota Soil Science Research Analytical Laboratory.

from the surface six inches of each of the four planting areas. Soil cores also were collected from the adjacent hardwood forest, and the area half stocked with volunteer trees and shrubs. Several newly germinated yellow-poplar seeds were planted in each soil core. When seedlings were well established, they were thinned to three per core. After 12 weeks the seedlings were washed from the cores and weighed. Results of this study have been published (Clark 1964), but are included here for comparison.

We suspected that endomycorrhizae might affect phosphorus absorption and the growth of yellow-poplar seedlings. So we collected 18 additional undisturbed, 0.8-gallon surface soil cores from the mixed hardwood forest area. Half of them were sterilized using methyl bromide. We then applied one of three levels of phosphorus fertilizer (0, 66, and 132 lbs/acre elemental phosphorus) to each core. Newly germinated yellow-poplar seeds were planted in each core. When well established, they were thinned to three per core. After 15 weeks the two largest seedlings in each core were washed from the soil cores and weighed.

RESULTS

Height Growth

All planted hardwoods grew slowly for the first 2 years. At 5 years, however, differences in height growth among the four areas were evident, and at 10 and 16 years, height differences were striking (figs. 1, 2, and 3). Analysis of variance for significant height differences between areas was not possible because only a single plot was located in each of the four areas. However, average heights for each species were consistent as shown by small standard errors of the mean. Standard errors at 5, 10, and 16 years were usually less than 1, 2, and 3 feet, respectively.

All trees planted on the nonstocked area had slow growth, and at 10 years they were not much taller than when planted. Mortality for red oak and black walnut was severe on the nonstocked area, top dieback and resprouting were common, and by 16 years all the oak and walnut were dead. Sweetgum and yellow-poplar survived much better on the nonstocked field, but growth was also slow for the first 10 years after planting. However, after 10 years, annual height growth



Figure 1.--These yellow-poplar on the nonstocked area were not much taller after 6 years than they were when planted.

for sweetgum and yellow-poplar was much better on the nonstocked area. At 16 years annual height for sweetgum on the nonstocked area averaged about 1.8 feet per year while, in contrast, sweetgum planted on the pine, fully stocked, and locust areas averaged about 2.2, 2.6, and 2.8 feet per year, respectively (fig. 4).

Growth of sweetgum and yellow-poplar was much better on the plots clearcut from the fully stocked and pine areas, and growth was outstanding on the plot clearcut from the black locust plantation.² At 10 years

²An additional plot was established 2 years earlier in a somewhat less eroded portion of this same locust plantation. Rapid growth of planted trees on this older plot was similar to growth on the locust area (fig. 3), but data could not be statistically combined with those used in the current analysis. After 18 years the four tallest red oak in each of the five rows averaged 19.3 ± 2.8 , black walnut 29.4 ± 3.3 , sweetgum 37.0 ± 0.9 , and yellow-poplar 48.8 ± 1.9 feet.



Figure 2.--These yellow-poplar on the locust area averaged almost 20 feet in height 7 years after planting.

sweetgum and yellow-poplar planted on the locust area were 17.7 and 28.0 feet taller, respectively, than they were on the nonstocked area; at 16 years they were 22.9 and 37.5 feet taller than on the nonstocked area. The outstanding 16-year height of sweetgum and yellow-poplar in the locust area was mostly due to exceptionally rapid growth from 5 to 10 years when trees grew 3 to 4 feet in height each year. But after the 10th year, annual height growth of both sweetgum and yellow-poplar in the locust area was somewhat slower, and was similar to growth in the fully stocked and pine areas.

Growth of red oak and black walnut also was better in the locust area than in the other areas. However, after the 10th year, annual height growth of oak and walnut in the locust area slowed somewhat, just as did yellow-poplar and sweetgum growth in the locust area.

Foliar Nitrogen

Foliar nitrogen for the four species differed greatly on the four areas (fig. 5).

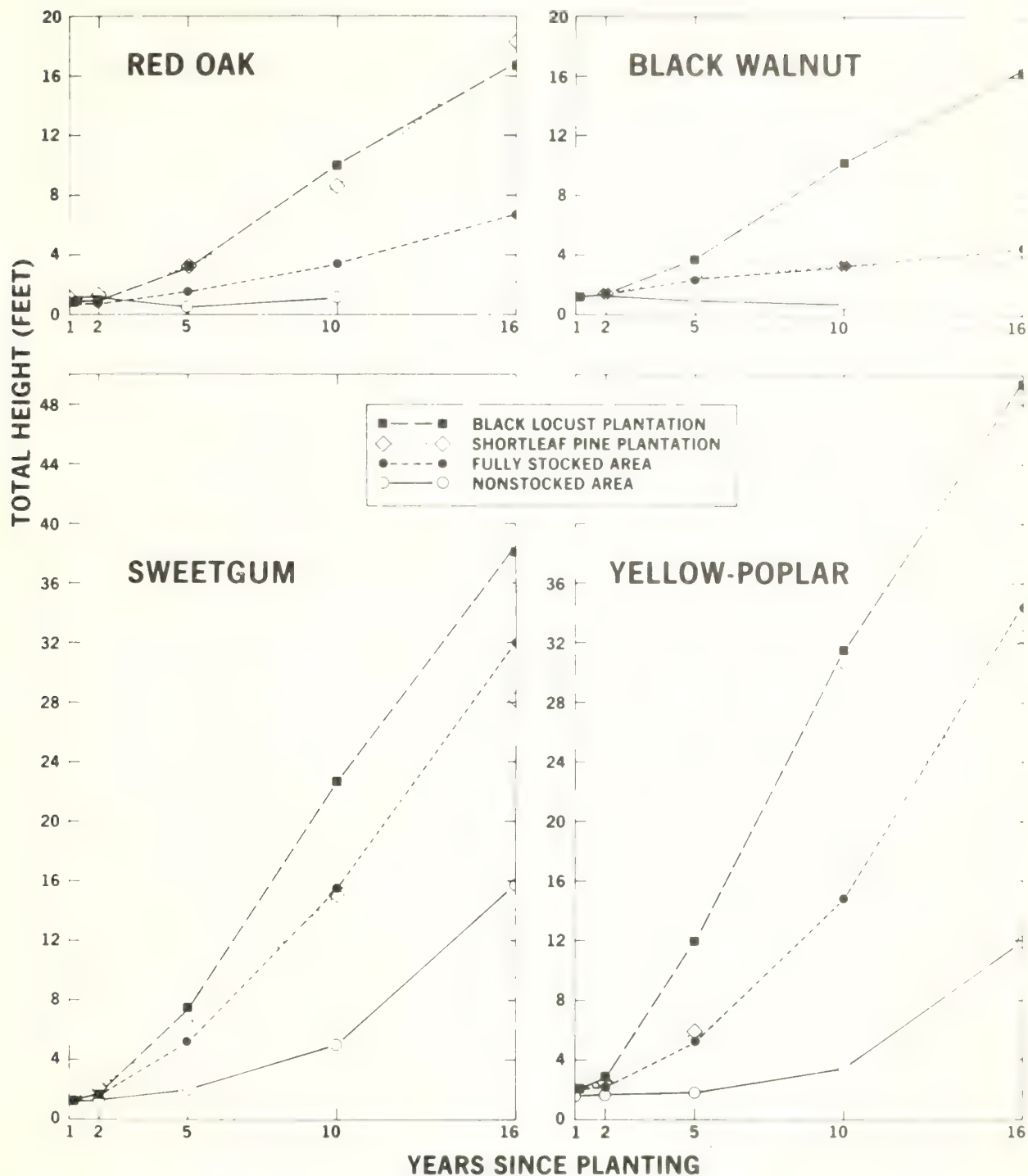


Figure 3.--Total height growth for four hardwood species planted in four areas.

For all species planted on the nonstocked area, 5-year foliar nitrogen levels were usually lower than for trees planted on the

other three areas. However, on the nonstocked area, 10-and 16-year foliar nitrogen increased for most species. This increase

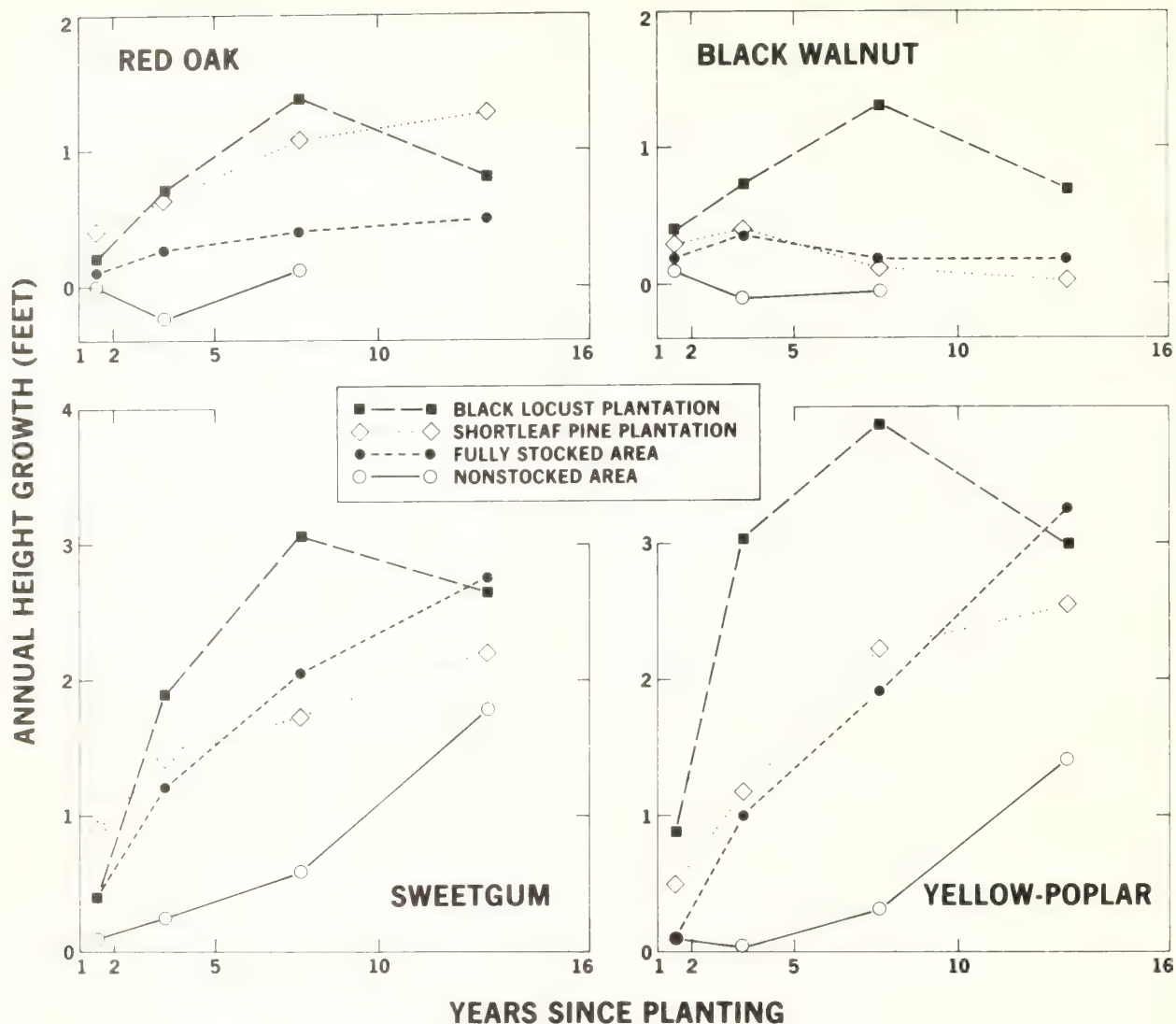


Figure 4.--Annual height growth for four hardwood species planted in four areas.

in foliar nitrogen on the nonstocked area corresponds to the increased growth in this area after 10 years for sweetgum and yellow-poplar. For all species planted on the locust area, 5-and 10-year foliar nitrogen was exceptionally high. However, foliar nitrogen decreased somewhat at 16 years for all species on the locust area which corresponds to the somewhat slower annual height growth after 10 years for all species planted on the locust area.

Annual height growth for black walnut, sweetgum, and yellow-poplar was usually related to foliar nitrogen at 5, 10, and 16 years (fig. 6). This relation was stronger

at 5 and 10 years. The weaker relation at 16 years was due to less foliar nitrogen and slower growth for trees on the locust area, and to more foliar nitrogen and more rapid growth for trees on the nonstocked area.

Foliar phosphorus and potassium levels were similar at 5 and 10 years for all species on all areas, thus little relation existed between height growth and foliar content of these elements.

Soil Characteristics

Soil descriptions and analyses made in 1962 show that texture is similar for all

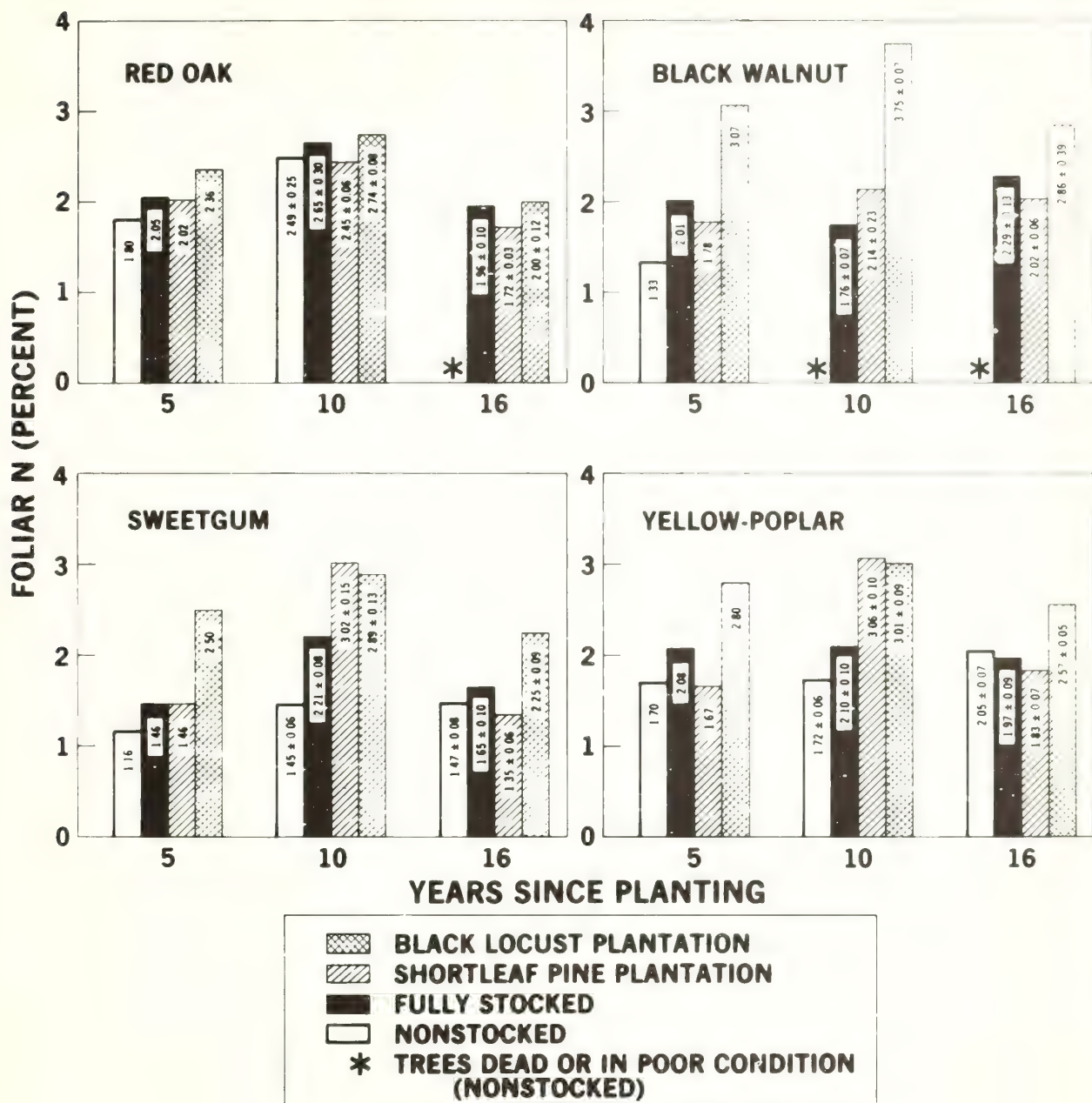


Figure 5.--Foliar nitrogen levels for four hardwoods at 5, 10, and 16 years since planting. (Standard errors of the mean were not calculated at 5 years because foliar samples were composited into a single sample for each of the four vegetal cover areas.)

study areas: silt content of the surface soil ranges from 59 to 63 percent, and clay content ranges from 26 to 29 percent (table 2). Surface soil depths (A1 and Ap horizons) also are similar (4 to 6 inches), except for the locust area where most of the original surface soil had eroded away. Depth to fragipan is about 20 inches for

the Tilsit soil of the nonstocked and fully stocked areas; fragipan depth is about 33 inches for the Zanesville soil of the pine area, and about 22 inches for the eroded Zanesville soil of the locust area. "Available" phosphorus was uniformly low (about 2 p/m), and "available" potassium ranged from 29 to 89 p/m.

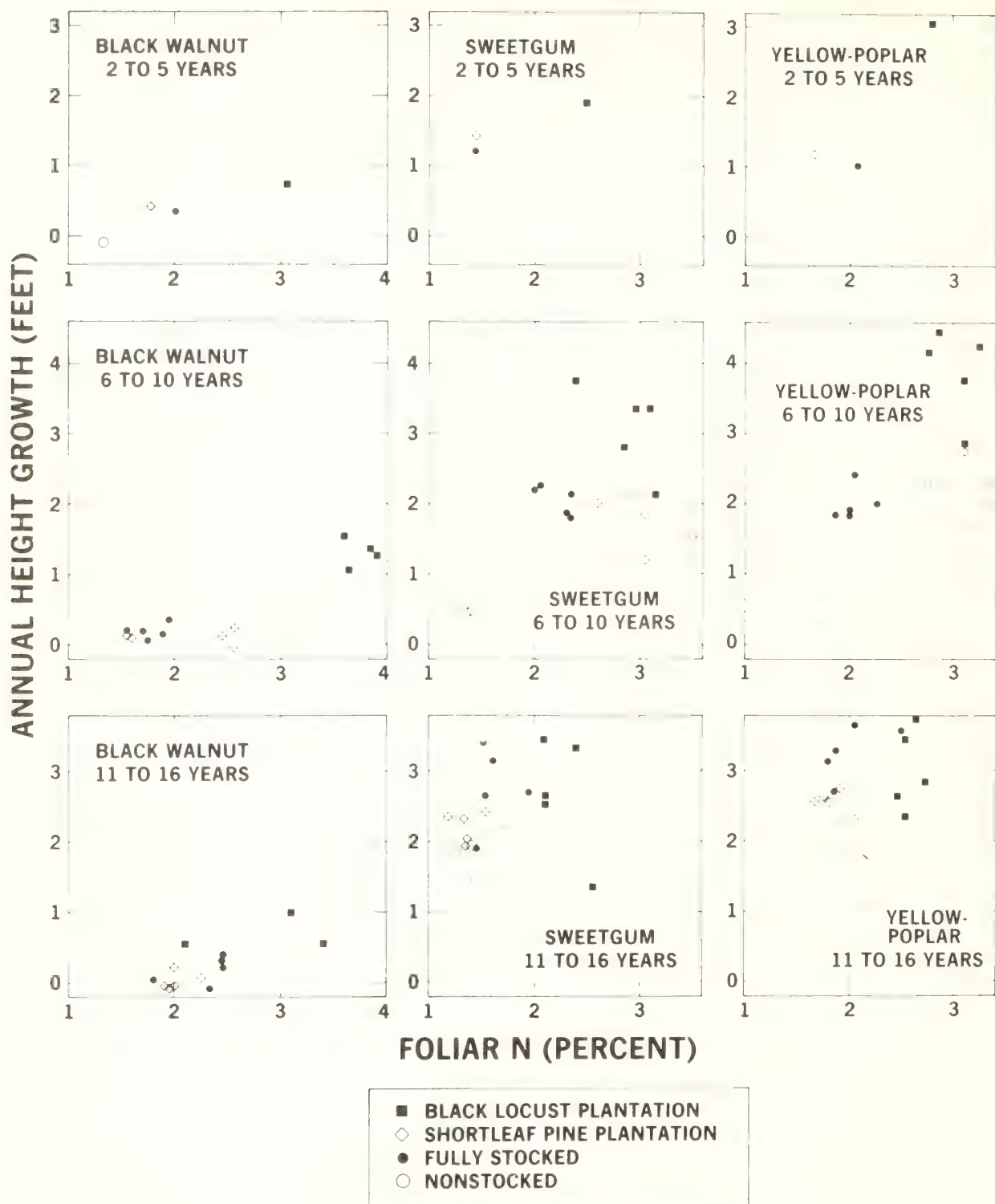


Figure 6.--Relation of annual height growth for black walnut, sweetgum, and yellow-poplar to foliar nitrogen levels at 5, 10, and 16 years since planting.

Measurements in 1962 showed that surface soil noncapillary pore volume, bulk density, and organic content differed greatly among the various study areas (fig. 7). The surface soil of the natural hardwood forest probably represents the original undisturbed surface soil conditions before clearing and farming. This surface soil has the highest organic content, lowest bulk density, and a high content of large, noncapillary pores. In contrast, the surface soil of the nonstocked area had little organic matter, and soils were dense and low in noncapillary pores; the locust area also had poor surface soil physical conditions because most of the original surface soil had been lost to erosion. Surface soils of the fully stocked and pine areas have surface soil physical conditions almost as good as those of the hardwood forest area. Thus, it appears that the presence of fully stocked stands of volunteer trees and shrubs, or planted pine, on agricultural land abandoned for about 23 years has changed surface soil physical conditions to approach the conditions of the hardwood forest area.

The surface soil layer in the locust area had the lowest noncapillary porosity, highest bulk density, and lowest organic content. These physical soil conditions are only a little better than those of the subsoil, probably because the surface soil layer of the locust area is mostly subsoil exposed by erosion before locust planting. The locust was planted in 1937 and clearcut for our studies in 1960, thus presence of black locust for 23 years apparently did not result in pronounced physical changes in what probably was mostly subsoil at the time the locust was planted.

Of course, subsoils are less porous and have less organic content than surface soils. Even so, subsoil physical conditions differed among the different vegetation conditions. The subsoil of the forest area, in contrast to the nonstocked area, had the most noncapillary pores, was less dense, and had the most organic content; these physical soil conditions were also fairly good in the fully stocked and pine areas. These somewhat better subsoil conditions for the hardwood forest, pine, and

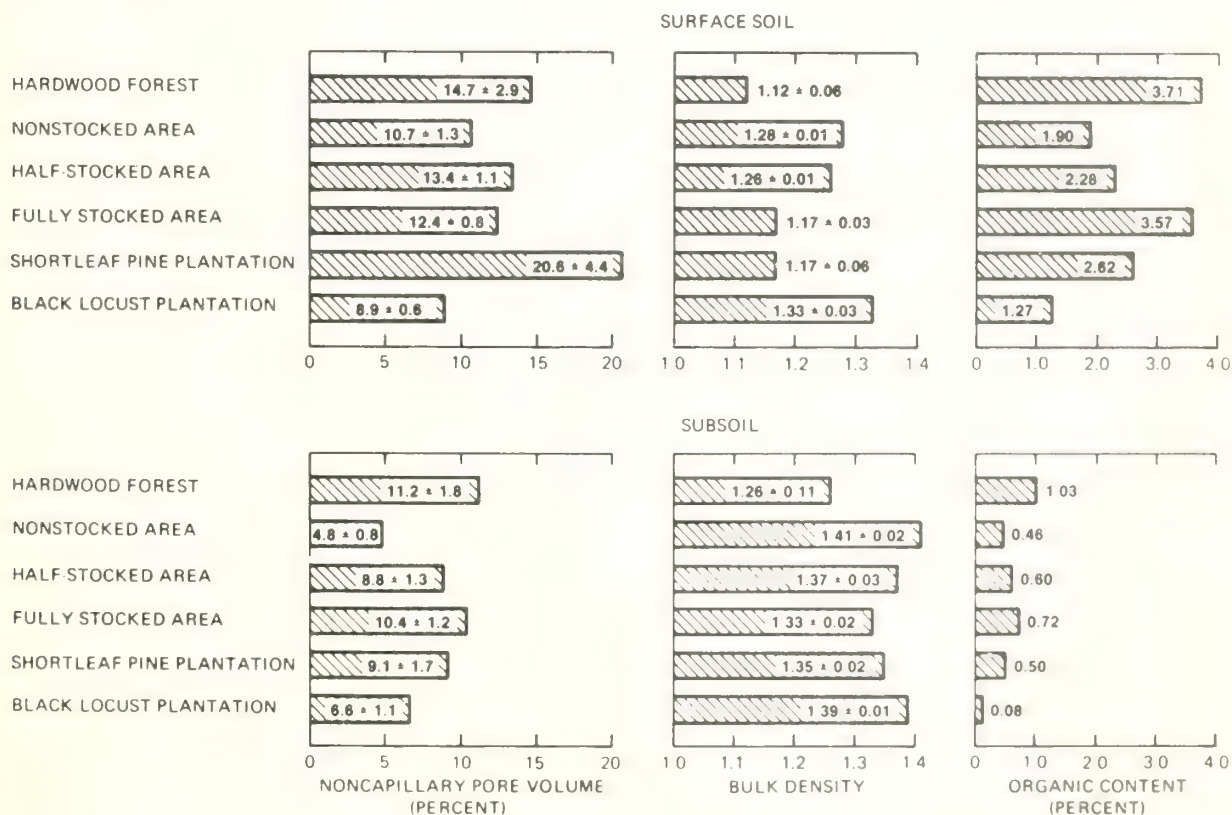


Figure 7.--Noncapillary pore volume, bulk density, and organic matter content for the surface soil (1 to 4 inches) and subsoil (9 to 12 inches) of the six study areas.

fully stocked areas probably are due to the long term presence of large, deep-rooted trees that produce subsoils having more root channels, more organic incorporation, and, as a consequence, more porous subsoils. Rolfe and Boggess (1973) observed similar subsoil differences for loess-derived soils in southern Illinois when they compared subsoils of grassy abandoned fields with subsoils of pine plantations.

Noncapillary pore volume, organic content, and bulk density are interrelated (fig. 8). Increased organic content is associated with decreased densities and with an increase in noncapillary pore volume. Naturally, more porous soils also have lower bulk densities.

Pot Culture Studies

Growth of yellow-poplar seedlings in undisturbed soil cores from the various study areas paralleled the growth of field planted seedlings (Clark 1964) (figs. 3 and 9). Yellow-poplar seedlings, as well as field-planted trees, had consistently poor growth in soil cores from the nonstocked area. Growth was better in cores from the fully stocked area and better yet in cores from the pine and hardwood forest areas. Exceptionally rapid growth was evident for yellow-poplar seedlings, as well as field-planted trees, in soil cores from the locust area.

Yellow-poplar seedlings in the soil cores, and in the field, usually grew better the greater the noncapillary porosity and organic content, and the less the bulk density (fig. 10). An exception was seedlings grown in soil from the black locust area where rapid growth occurred despite adverse soil physical conditions. The locust area probably has abundant soil nitrogen, as indicated by the large content of foliar nitrogen (fig. 3), and this large nitrogen supply might have more than offset the effects of poor physical soil conditions. Nitrogen relations in the locust area were so unlike those in the other areas that direct growth comparisons would be misleading. So, values for the locust areas were not included in the calculations illustrating how growth is correlated with noncapillary pore volume, bulk density, and organic content (fig. 10).

Yellow-poplar seedlings did not respond to phosphorus fertilizer when grown

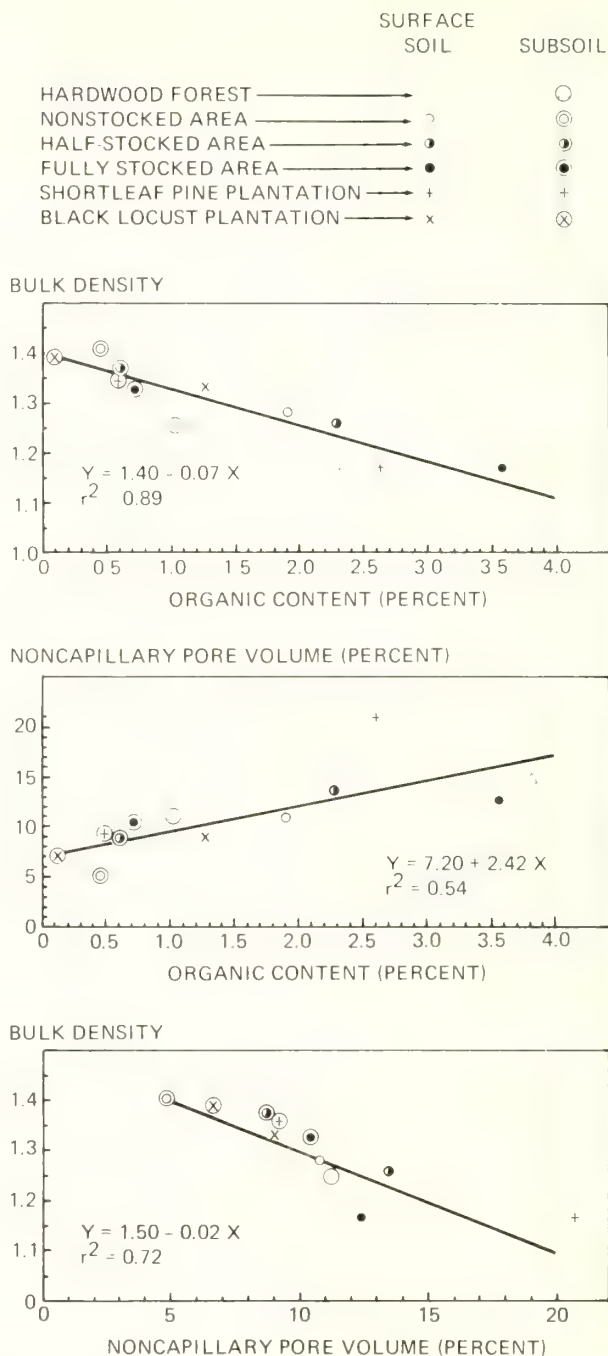


Figure 8.--Relation of noncapillary pore volume, bulk density, and organic matter content.

in undisturbed and unsterilized soil cores. After 15 weeks the fresh weight of seedlings fertilized with 0, 66, and 132 lbs/acre elemental phosphorus averaged 6.20 grams. In contrast, seedlings did respond significantly (0.05 and 0.01 level) to phosphorus

FRESH WEIGHT (GM)

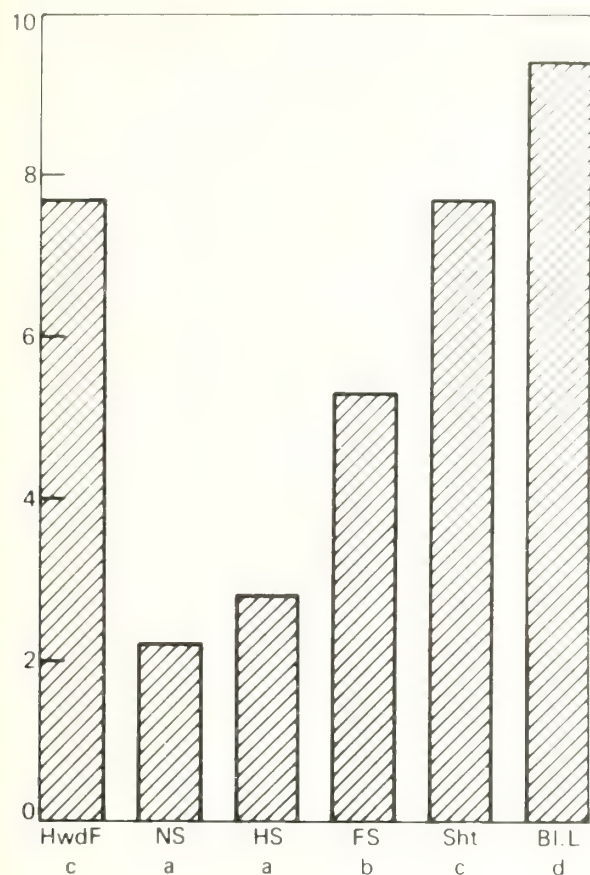


Figure 9.--Fresh weight of yellow-poplar seedlings grown 12 weeks in undisturbed surface soil (0 to 6 inches) cores collected from six vegetative cover areas. (Areas having the same letter are not significantly different (0.01 level). HwdF = hardwood forest, NS = nonstocked area, HS = half-stocked area, FS = fully stocked area, Sht = shortleaf pine plantation, and Bl.L = black locust plantation.

fertilizer when grown in undisturbed cores that had been sterilized with methyl bromide. After 15 weeks the fresh weight of seedlings fertilized with 0, 66, and 132 pounds of phosphorus averaged 1.33, 3.72, and 4.01 grams, respectively.

DISCUSSION AND CONCLUSIONS

This study is based only on a single plot in each of four vegetative cover areas. Thus, our results should be considered as a case history observation of tree growth

FRESH WEIGHT (GM)

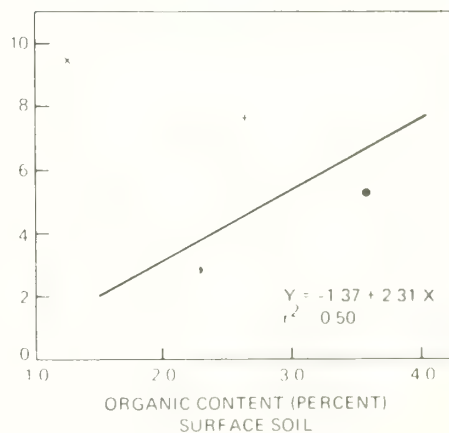
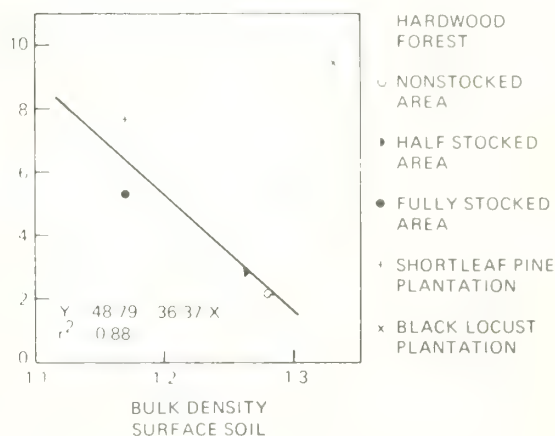
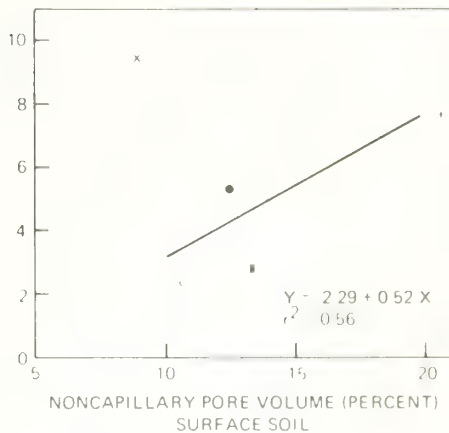


Figure 10.--Weight of yellow-poplar seedlings grown in undisturbed surface soil (0 to 6 inches) cores collected from six vegetative cover areas was related to surface soil structure. (Correlations shown do not include seedlings grown in soil cores from the black locust area.)

on an abandoned field having contrasting vegetal cover conditions. Even though our study lacks statistical replication, we still consider the results meaningful because (a) we have observed great differences in growth on the four vegetal areas, (b) we have lengthy observations--16 years, and (c) we have found tree growth to be closely related to several important physical, chemical, and biological soil factors. Because of these many relations, we conclude that the striking growth differences we have observed are due to a complex of several interrelated physical, chemical, and biological factors rather than a single limiting factor. We hope our observations and hypotheses will provide some meaningful basis for future studies that explore in more detail the complex growth relations of hardwood trees on abandoned agricultural fields.

Physical Soil Relations

Some of the differences in soil physical conditions we observed in 1962 could have existed at the time the field was abandoned in the mid-1930's. Soils frequently change, even within small areas, but we do not believe normal soil variation is responsible for most of the pronounced differences in soil physical conditions among our four study areas. Obviously, soil conditions in the eroded locust plantation areas were initially much different from those in the other three areas. However, soil conditions for the nonstocked, fully stocked, and pine areas probably were similar at the time the field was abandoned. The three areas are adjacent, they have the same topographic position, and their surface soil depths and profile textures are almost identical (table 1). So, we attribute most of the present physical soil differences to the influence of different kinds of vegetation present for at least 23 years since land abandonment.

Our observations on differences in porosity, bulk density, and organic content agree closely with other studies showing pronounced soil changes resulting from old-field succession, or from planting trees on agricultural land (Auten 1933, 1941, 1945; Billings 1938; Coile 1940; Byrnes and Kardos 1963; Challinor 1968). Similar soil physical changes due to vegetal differences also have been reported for an abandoned field in southern Illinois having loess-derived soils (Rolfe and Boggess 1973, Fisher *et al.* 1975).

The soil physical differences we have observed are closely associated with the large growth differences for trees planted on our four areas. Better tree growth with better soil physical conditions also has been observed elsewhere (Youngberg 1959, Foil and Ralston 1967, Minore *et al.* 1969, Hatchell 1970). Agricultural crops also grow better with more favorable physical soil conditions. This is because soils that are porous and loose are better aerated, have more favorable temperature relations, root respiration is improved, mechanical resistance to root extension is lessened, and roots are better able to absorb soil moisture and nutrients (Lutz 1952, Russell 1952, Barley and Greacen 1967, Danielson 1972, Taylor *et al.* 1972). These relations between physical soil conditions and root physiology probably are partially responsible for the close associations we have observed between tree growth and noncapillary pore space, bulk density, and organic content (fig. 10).

Nitrogen Relations

Nitrogen-fixing nodules occur on black locust roots. Locust litter also returns large amounts of nitrogen to the soil, thus soils under locust stands contain abundant nitrogen (Ike and Stone 1958). Soil nitrogen contributed by black locust has long been known to stimulate growth of associated trees on both abandoned fields and strip-mined land (McIntyre and Jeffries 1932, Chapman 1935, Chapman and Lane 1951, Finn 1953). Likewise, hardwoods planted on our locust plot contain large amounts of foliar nitrogen and the sweetgum and yellow-poplar are growing remarkably fast. Apparently much of the nitrogen contributed by the locust remains 16 years after the locust was cut, and this nitrogen still is stimulating rapid tree growth.

Finn (1953) found that yellow-poplar, sweetgum, black walnut, and red oak interplanted with locust grew rapidly and had large amounts of foliar nitrogen. His results closely parallel the rapid growth and large amounts of foliar nitrogen we observed for these same species planted on our locust plot. We as well as Finn found that these hardwood species planted on abandoned fields without locust grew slowly and contained only small amounts of foliar nitrogen.

Early growth was outstanding on the eroded soil of the locust area even

though the dense soil was low in organic matter and noncapillary pores. The abundant supply of nitrogen in the locust area perhaps compensated for poor physical soil conditions and thus stimulated early tree growth. But the large supply of nitrogen inherited from the previous locust stand may be diminishing with time, thus resulting in somewhat slower later growth. Measurements at 16 years of trees planted on the locust plot indicate that the initial high foliar nitrogen levels and initial rapid annual height growth may indeed be diminishing 10 years after planting.

At age 10 sweetgum and yellow-poplar planted on the fully stocked and pine areas also had more foliar nitrogen and were growing faster than trees on the nonstocked area. Finn (1953) likewise observed that hardwoods underplanted in a decadent shortleaf pine plantation in southern Illinois had more foliar nitrogen and better growth than hardwoods planted in a nearby abandoned field. One possible explanation for the better growth we observed is that the surface soils of the fully stocked and pine areas had more organic matter, and hence more soil nitrogen, than the surface soil of the nonstocked area. Another possible explanation is that soil organisms in the pine or hardwood root zones may mineralize or otherwise extract some fraction of soil nitrogen resistant to organisms in the root zone of the grasses in the nonstocked area. This was suggested by a study in New York (Fisher and Stone 1969, Stone and Fisher 1969) where total amounts of soil nitrogen and phosphorus were similar in abandoned fields, conifer plantations, and in the border zones. However, they found that more available nitrogen occurred in the conifer soils, presumably because of better mineralization of soil organic matter.

Endomycorrhizae Relations

Before concluding that soil physical conditions and nitrogen were exclusively responsible for our observed growth differences, we also considered the possible influence of other nutrients and soil mycorrhizae. Pot culture studies were designed to observe the role of these additional factors as well as complement the field studies.

Soil samples from all study areas contained little readily available phosphorus

(table 2). This prompted a study of the response of pot-grown black locust and tomato (*Lycopersicon esculentum* Mill.) seedlings to nitrogen, phosphorus, and potassium fertilizers. Locust and tomato seedlings grown in disturbed soil samples collected from the hardwood forest, nonstocked, pine, and locust areas responded strongly to phosphorus fertilization (Hannah and Kohnke 1964).

Further studies were then made using yellow-poplar seedlings grown in undisturbed soil cores collected from the hardwood forest area. As already described we found no response to phosphorus fertilization for yellow-poplar seedlings grown in undisturbed soil cores, even though black locust and tomato grown in disturbed soil had responded to phosphorus (Hannah and Kohnke 1964). In contrast, yellow-poplar did respond strongly to phosphorus when growing in undisturbed cores that had been sterilized. Seedling roots were not examined in this study. However, other studies (Clark 1961, 1964), suggest that yellow-poplar roots growing in the unsterilized cores were infected with endomycorrhizae and thus able to absorb sufficient phosphorus despite low levels of "readily available" soil phosphorus. In contrast, yellow-poplar seedlings growing in the sterilized cores probably lacked endomycorrhizae; this apparently resulted in insufficient phosphorus absorption, and thus seedlings in sterilized soil responded to phosphorus fertilization. This view is supported by studies showing that vesicular-arbuscular endomycorrhizae present on roots of yellow-poplar and sweetgum result in increased uptake of soil phosphorus (Gray and Gerdemann 1967).

The rapidly growing yellow-poplar seedlings growing in undisturbed cores from the hardwood forest, the pine area, and the locust area had well developed endomycorrhizae (Clark 1964).³ But the slow-growing seedlings in undisturbed soil cores from the nonstocked area were "weakly" infected and the hyphae within seedling root cells appeared to be disintegrating. Clark (1964) also found that yellow-poplar seedlings grown in screened surface soils from the hardwood forest were much smaller than seedlings grown in undisturbed cores of the

³Examinations for endomycorrhizae were made by Edward Hacksaylo, Plant Physiologist, USDA Forest Service, Beltsville, Maryland.

same soil. He concluded that screened soils as well as soils from the nonstocked area were more dense, less porous, and less aerated. These poorer physical soil conditions thus may have affected endomycorrhizal activity and hence the ability of yellow-poplar seedlings to absorb sufficient soil nutrients and moisture. Later reports on endomycorrhizae also emphasize that good soil physical conditions result in better oxygen supply and greater root metabolic activity, thus favoring endomycorrhizal development and better phosphorus uptake for trees growing on infertile soils (Gerdemann 1968, Gray 1969, Harley 1969). Apparently the physiological activity of endomycorrhizae on our hardwood seedling roots was closely related to soil physical conditions and to the ability of the hardwood seedlings to absorb sufficient amounts of soil nitrogen and phosphorus. Additional studies of these interrelations may more precisely define their role in hardwood tree growth.

Allelopathic Relations

Several herbaceous species occurring in the early stages of old-field succession contain allelopathic compounds that inhibit nitrogen-fixing and nitrifying bacteria (Rice 1964, 1974). The broomsedge that dominated our nonstocked area has allelopathic compounds in both roots and shoots that inhibit root nodulation and the growth of legumes. Such allelopathic compounds are an important competitive mechanism favoring plants having low nitrogen requirements. For example, in eastern Oklahoma allelopathic compounds produced by broomsedge inhibit the growth of several competing plant species, thus enabling broomsedge to dominate old fields for many years (Rice 1972). Also allelopathic compounds in broomsedge reduced the growth of loblolly pine (*Pinus taeda* L.) seedlings.⁴

The broomsedge dominating the nonstocked area may have produced allelopathic compounds that inhibited the growth of our planted hardwoods. Sassafras, present in our fully stocked area, has recently been shown to produce allelopathic compounds

that influence old-field succession in Tennessee (Gant and Clebsch 1975). Broomsedge in our nonstocked area may have produced allelopathic compounds that inhibited nitrogen-fixing soil organisms and also endomycorrhizal development. As a result, the supply of nitrogen, phosphorus, and other nutrients may have been limited, thus resulting in poor early growth of our planted hardwoods. But the initially slow-growing hardwoods planted in the nonstocked area gradually attained dominance after 10 years, thus reducing the density of the broomsedge. So the influence of allelopathic compounds produced by broomsedge may be diminishing, judging from the increased foliar nitrogen and increased annual height growth observed at 16 years for sweetgum and yellow-poplar planted on the nonstocked area.

APPLICATION OF RESULTS

The reasons are complex for the striking differences in growth that we observed for hardwoods planted on an abandoned field having contrasting vegetal cover conditions. Apparently several important physical, chemical, and biological soil factors are involved and more detailed studies are needed before we can fully understand their complex interrelations.

Even though the basic reasons for our growth differences are complex, hardwoods obviously grow much faster when planted on old fields where soils have been modified physically, chemically, and biologically by the presence of well stocked stands of trees. The time required for these soil modifications is uncertain, but our studies on a single abandoned field indicate that soil conditions are improved for planted hardwoods during 23 years under forest cover.

Shortly after abandonment many upland old fields are invaded by aggressive, brushy vegetation. Many such areas are good sites for trees but in the past were usually not planted because land clearing and brush control were difficult and expensive. Our studies suggest that on good upland sites this tree and shrub cover will improve growing conditions for more desirable hardwoods. Therefore, such areas can be considered good hardwood planting sites now that better mechanical and chemical methods are available for brush control and for converting brushy areas to desirable hardwood plantations.

⁴Priester, D. S., and M. T. Pennington. 1976. Inhibitory effects of broomsedge (*Andropogon virginicus* L.) on the growth of young loblolly pine (*Pinus taeda* L.) seedlings. USDA For. Serv., Southeast. For. Exp. Stn., Asheville, North Carolina: (Unpublished Ms.)

Our studies also indicate that pine stands improve growing conditions for planted hardwoods. So, on good upland sites, conversion to commercially valuable hardwoods might be desirable following an initial rotation of pine. This was done in southern Illinois where yellow-poplar made excellent growth when planted in a clearcut portion of a shortleaf pine plantation (Young *et al.* 1969). Furthermore, an initial rotation of nitrogen-fixing tree species, such as black locust, alder (*Alnus* spp.), or autumn-olive (*Elaeagnus umbellata* Thunb.)⁵ may improve soil conditions for certain eroded and less favorable sites, thus better growth and survival might be achieved when these areas are converted to valued hardwoods.

⁵Unpublished 7-year results show significant increases in height and diameter growth for black walnut when interplanted with autumn-olive (D. T. Funk, North Cent. For. Exp. Stn., Carbondale, Illinois).

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Hardwoods were planted in a long-abandoned field. Growth was poor in a grassy area, better in areas formerly having natural trees or planted pine, and outstanding in an area formerly having planted black locust. Improved growth was associated with better soil structure and more foliar nitrogen.

OXFORD: 181.32:182.21. KEY WORDS: old-field succession; physical, chemical, and biological soil conditions; foliar nitrogen.

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NORTHERN WISCONSIN SNOWMOBILERS:

**Their Characteristics
and Management Preferences**

EARL C. LEATHERBERRY

CONTENTS

The Study Area	2
Study Procedures	2
Study Results	2
Discussion	3
Conclusions	4
Literature Cited	4

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NORTHERN WISCONSIN SNOWMOBILERS: THEIR CHARACTERISTICS AND MANAGEMENT PREFERENCES

Earl C. Leatherberry

Before the 1950's, there were only a few hundred snowmobiles in North America and most were used primarily for nonrecreation purposes. Public land managers did not see snowmobile use as a threat to the environment nor as a source of conflict with other recreation uses. However, within a decade (1962 to 1972) the sale of snowmobiles grew from 10,000 to 587,000 units per year (International Snowmobile Industry Association 1973). And today there are an estimated 2.6 million snowmobiles in operation in the United States.

In reaction to the relatively rapid increase in the use of snowmobiles, various segments of the public began to call for measures to regulate their use. Public land managers also began to notice environmental damages from the indiscriminate use of snowmobiles (Butcher 1972). In haste to deter apparent environmental damages and to appease public opinion, some public land management agencies adopted poorly conceived regulations and policies (Butler 1974). In some instances, regulations and policies were improvised or copied from other areas without reference to or consideration of local conditions.

In 1972, President Nixon issued Executive Order 11644--"The Use of Off Road Vehicles on Public Lands". In the order, the President called for each Federal land management agency to designate specific areas and trails on public land where the use of off-road vehicles may be permitted, and areas where they may not be permitted. Efforts to respond to this order have been accompanied by intensive feeling on both sides. Frequently, for the same decision, managers have been abused on the one hand for being snowmobile advocates and on the other for being antisnowmobile.

Because of the controversy surrounding the establishment of snowmobile regulations, managers should know something of their clientele's perception of the issues. For example, past research has shown that management decisions are sometimes made without adequate knowledge of the user and his attitudes about the issues (Moeller *et al.* 1974). Research has also shown that land managers are not always able to objectively perceive management policies that are acceptable to the user public (Hendee and Harris 1970).

As a first step toward filling this gap, a study was begun to gain some insight into how snowmobilers felt about alternative management strategies for regulating snowmobile use on public land. The study was intended not only to determine an average group response to the management alternatives but also to identify differences that may exist between different groups of snowmobilers.

The study focused on snowmobilers who resided close to large expanses of public land. It was presumed that those snowmobilers would be most affected by a particular management decision. For simplicity, the study focused on National Forest land in northern Wisconsin where management options for regulating snowmobiles and other off-road vehicles were under consideration.

The study was not designed to deal directly with policy nor does it advocate any particular management stance. It was designed solely to identify and survey a target population that, presumably, was aware and interested in policy issues.

THE STUDY AREA

The study area was the northern two thirds of Wisconsin (fig. 1). The area is sparsely populated with a density of 35 people per square mile. In 1975, there were 141,936 registered snowmobilers (53 percent of the State's total) or one for nearly every 9 people. More than 4 million acres of land, more than 20 percent of the total area, is publicly owned (10 percent county, 4 percent State, and 7 percent Federal). The Chequamegon and Nicolet National Forests represent the largest contiguous blocks of public land. Much of the area's potential for snowmobiling exists on these two Forests. The acreage essentially is unimproved, but old logging roads and trails can be found throughout the Forests. Most parts of the two Forests are within easy driving distance of the study area's villages and towns. In fact, any point within the study area is within approximately 100 miles of one of the Forests.



Figure 1.--Location of the study area.

STUDY PROCEDURES

In November 1973 a questionnaire, designed by George Banzhaf and Company of Milwaukee, was mailed to 1,200 randomly selected telephone subscribers who resided in Wisconsin and Michigan and 400 predetermined community leaders (George Banzhaf and Company 1974). The questionnaire was also submitted to a group of 260 snowmobilers, residents of the study area, who were participating in a wildlife-snowmobile research project at the Clam Lake Field Station of

the University of Wisconsin in February and March of 1974.

From all completed questionnaires received a sample was selected consisting of those heads-of-household who indicated: (1) they or a member of their family were active snowmobilers, and (2) they resided within the established study area. A total of 225 respondents met the criteria for inclusion in the sample. Although not randomly selected, the sample is considered to be representative of snowmobilers of the study area.

STUDY RESULTS

The "typical" respondent was more rural oriented than the average resident of the study area and was better off financially. He lived on a farm or in a nonfarm rural setting or in a small town. He was employed as a craftsman or blue-collar worker and earned more than \$13,000 per year, much more than the \$7,600 average for the area.

More than half the respondents were avid fishermen and hunters (table 1). Recreational activities less intensively pursued included, trail bike riding, snowshoeing, dune buggy riding, and canoeing. The low participation rates, especially on a regular basis, for trail bike riding and dune buggy riding indicates that the use of other off-road vehicles is apparently not widespread among the snowmobilers surveyed.

Sixty five percent reported that they belonged to at least one conservation group or outdoor recreation organization. Membership in snowmobile clubs was the first-mentioned organization by 53 percent of the respondents. Memberships in hunting, fishing, and sportsmen-related organizations were mentioned first by 8 percent of the respondents. The remaining clubs and organizations reported were mostly community-oriented groups, such as property associations and youth organizations.

The respondents were asked to express agreement or disagreement with several policy statements regarding snowmobile use, ranging between the extremes of prohibiting all use to placing no restrictions on use (table 2).

Most respondents agreed that use should be restricted to trails, that certain areas

Table 1.--*Participation rates in selected outdoor recreation activities by respondents*
(In percent)

Activity and number of respondents	Participation rates (number of times past 3 years)			
	None	Once	2 to 10 times	More than 10 times ¹
Fishing (N=225)	11	2	27	60
Hunting (N=225)	28	2	28	58
Long hikes (more than 1 mile) (N=221)	41	8	25	26
Short hikes (nature trails) (N=224)	29	10	36	25
Camping (N=218)	24	11	41	24
Bicycling (N=220)	48	2	27	23
Horseback riding (N=221)	67	8	12	13
Trail bike riding (N=221)	68	6	14	11
Snowshoeing or cross-country skiing (N=221)	76	5	10	8
Canoeing (N=220)	63	9	22	6
Dune buggy or all terrain vehicle riding (N=220)	79	8	9	4

¹Considered to be on a regular basis.

Table 2.--*Respondent's reaction to five alternatives for regulating snowmobile use on National Forest land*
(In percent)

Alternative and number of respondents	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
Set aside areas for no use (N=224)	39	46	6	6	3
Restrict to trails or routes (N=220)	32	37	4	19	9
Allow use anywhere in certain areas both on and off trails (N=224)	12	40	12	23	13
Prohibit all use (N=224)	3	1	4	50	42
Do not restrict use (N=220)	3	10	2	46	39

should be set aside where no use is allowed, and that use should be allowed in certain areas both on and off trails. Very few advocated unrestricted use or prohibiting all use. Attitudes were fairly clear-cut toward all but one alternative statement: setting aside areas for use both on and off trails. Here there was no strong consensus.

On the assumption that the greatest opposition to proposed regulations to limit snowmobile use would come from snowmobile club members, responses from members of such

groups were analyzed separately. The assumption proved false--there was no significant differences in viewpoint between members and nonmembers (table 3).

DISCUSSION

The snowmobilers surveyed felt that some types of restrictions were necessary on snowmobiles that operate on public land. They agreed that vehicles should be restricted to trails and that some areas should be

Table 3.--Differences between respondents
in mean intensity of feeling toward use
restrictions

Alternative	Mean scores ¹	
	Affiliated respondents (N = 119)	Nonaffiliated respondents (N = 106)
Set aside areas for no use	0.94	0.81
Restrict to trails or routes	1.34	1.27
Allow use anywhere in certain areas both on and off trails	1.79	1.91
Prohibit all use	3.29	3.28
Do not restrict use	3.12	3.13

¹Values range from 0 to 4. Value of 0 indicate strong agreement, value of 4 strong disagreement.

preserved for no vehicle use. But when asked if vehicles should be allowed to operate anywhere in certain areas, both on and off trails, the composite opinion was close to a neutral or undecided stance. This stance may be related, in part, to the ambiguity of the statement. Nevertheless, one might suspect that snowmobilers would strongly favor off-trail use on public land and that they would be more inclined to prefer less restrictions. Apparently, the snowmobilers surveyed also appreciate other outdoor recreational activities and values. For example, respondents surveyed perceived themselves as "outdoor men" actively engaging in hunting and fishing as recreation activities. They may engage in snowmobiling because during the winter few other outdoor recreation alternatives are available.

Membership in snowmobile clubs did not have a statistically significant influence on attitudes toward the suggested management alternatives. However, research results have shown that advocacy organizations, such as snowmobile clubs, are formed to present the views of members on specific local problems (Irland and Vincent 1974). Typically, snowmobile clubs, through their spokesmen, express great concern about proposed regulations to delimit the area in which snowmobiles are allowed to operate. Perhaps in the future, affiliation with snowmobile clubs will be more important to the individual snowmobiler. Two major factors point in that direction. First, there is an apparent leveling off in the number of novice snowmobilers (Knopp and Tyger 1973). Second, the present trend in regulating snowmobile use appears to be toward designating use areas. So, the need for a more uniform and pragmatic mechanism to advocate the goals of snowmobilers will probably increase. The recent growth in the

number of snowmobile user organizations and members suggests that snowmobilers are, in fact, becoming more organized. In Wisconsin, such groups currently represent approximately 47 percent of all snowmobilers (Wisconsin Department of Natural Resources and Upper Great Lakes Regional Commission 1974). Given a continued increase in membership, public land managers may be destined to face increasingly organized pressures from snowmobilers for what they perceive to be their fair share of the action.

CONCLUSIONS

The rapid growth of the use of snowmobiles in the late 1960's and early 1970's has begun to subside--the popularity of snowmobiling seems to be leveling off. However, the management concerns related to the use of snowmobiles on public land are still prevalent.

Our study indicates that snowmobilers as a group hold no radical viewpoints, one way or the other, on snowmobile use. They would seem to be amenable to reasonable regulations regarding the use of their vehicles. This attitude should encourage and guide land managers in making decisions concerning snowmobile use.

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1976. Northern Wisconsin snowmobilers: their characteristics and management preferences. USDA For. Serv. Res. Pap. NC-135, 5 p., illus. North Cent. For. Exp. Stn., St. Paul, Minn.

This paper provides an insight into how snowmobilers feel about various management strategies to regulate snowmobile use on public land. The paper provides the composite opinion of snowmobilers and their opinion based on whether they were members of snowmobile clubs.

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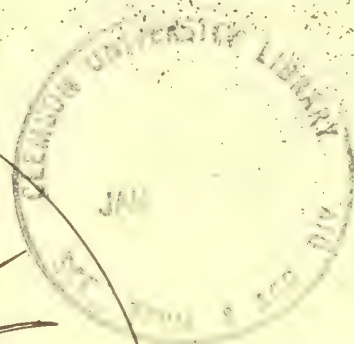
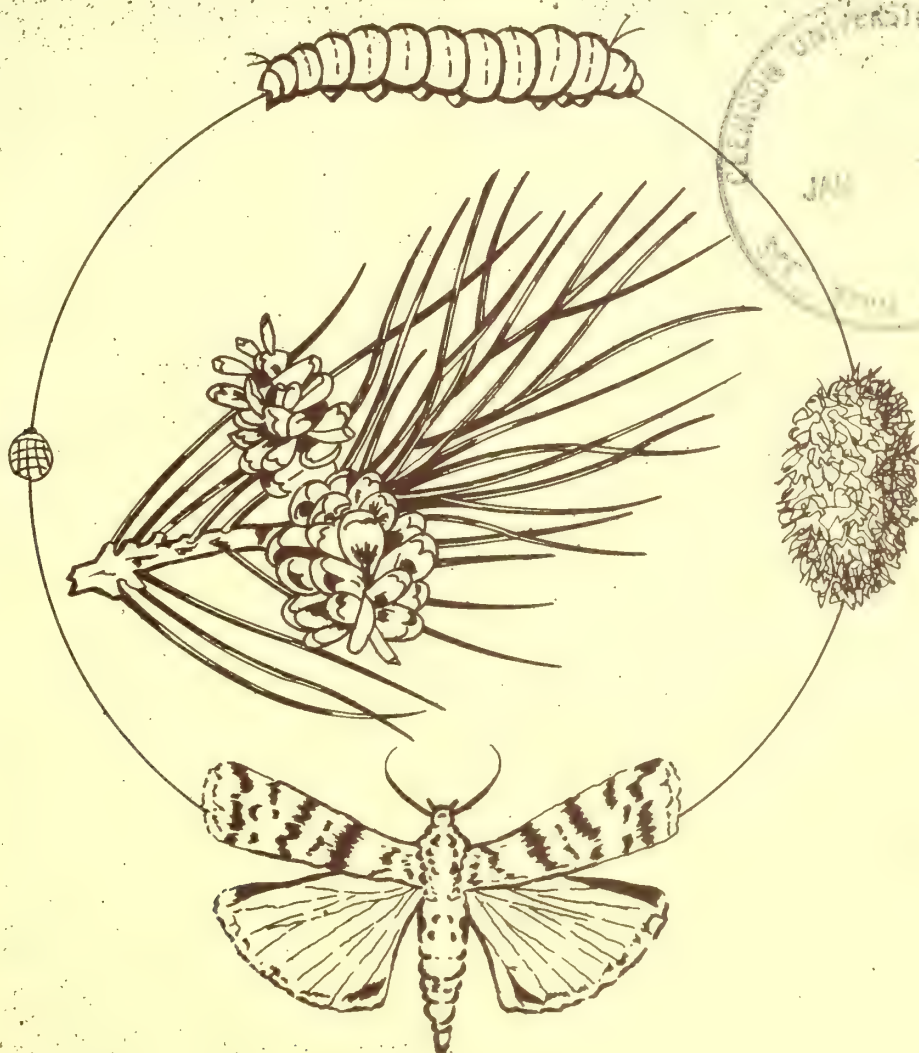
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DISTRIBUTION OF THE CONE INSECT, *Dioryctria disclusa*, IN RED PINE TREES

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DISTRIBUTION OF THE CONE INSECT, DIORYCTRIA DISCLUSA, IN RED PINE

William J. Mattson

In North and Central America, at least 12 species of *Dioryctria* moths attack the reproductive structures of conifers, especially the diploxylon or "hard" pines (Barcia and Merkel 1972, Mutuura and Munroe 1972, Coulson *et al.* 1972). Many are notorious for their destruction of cones in seed orchards and seed production areas (Mattson 1968, Sartor and Neel 1971, Coulson and Franklin 1970).

The general biology and ecology of cone feeding *Dioryctria* species are fairly well established (Barcia and Merkel 1972). However, detailed information is lacking about their host selection processes and spatial distributions. The distributions of insects both within and among trees are assumed to follow the distributions of their foods, which in addition to cones, may include buds, shoots, cankers, and male strobili.

In red pine, *Pinus resinosa* Ait., early-stage larvae of *D. disclusa* Heinrich feed in male strobili for about two weeks, i.e. until the strobili have begun to desiccate severely after dissemination of pollen (Lyons 1957a) after which, the larvae search for year-old cones. Each late-stage larva needs at least 2 cones to complete development in species (which have small cones) such as red, jack, *P. banksiana* Lamb., and Scots, *P. sylvestris* L., pines. Rarely do larvae share cones except when feeding is virtually completed and they have begun to pupate.

If *D. disclusa* larvae follow their food, a question arises about which food is followed because male and female strobili

have different spatial distributions. For example, male strobili occur predominantly in the lower one-half; female strobili in the upper one-half crown (Matthews 1963, Hard 1964). Trees also vary greatly in their capacities to produce each type of strobili. Nonvigorous or shaded trees can often produce an abundance of male but not many female strobili (Matthews 1963, 1969). Whereas, open-grown trees can usually produce large crops of both kinds of strobili (Matthews 1969, Puritch 1972). Furthermore, there is a temporal distribution problem in trees that are capable of producing both kinds of strobili: How often is the abundance of male strobili correlated with the abundance of year-old female strobili? This is not known.

The cues females respond to when selecting trees for oviposition are unknown. One would expect them to select trees with an abundance of future food because competition for food among red pine cone insects can be severe (Lyons 1957b, Mattson 1968, 1971). Asher (1970) provided evidence that *Dioryctria* moths may be able to detect trees bearing potentially large cone crops when he discovered that electroantennograms of *D. abietella* (D.&S.) are highly responsive to certain volatile extractants from conelets of slash pine, *P. elliotii* Engelman.

At the time of oviposition (late July for *D. disclusa* in the northern Great Lakes region), there are both cones and conelets on the trees but only few desiccated male strobili. Therefore, if females orient to food per se when seeking oviposition sites, it must be to either cones, conelets, or both.

The objectives of this study were threefold: (1) to compare the distribution of larvae with that of their food both within and among trees, and (2) to determine the significant sources of variation in insect densities in order to facilitate future insect sampling, and (3) to relate cone damage among trees to food and insect abundance.

METHODS

In 1967, I studied the within-tree distributions of early and late larvae and male and year-old female strobili at the Birch Hill seed production area (SPA) (64 years, 65 ft., 63 stems/acre) in Itasca Co., Minn. During 1968-1970 I studied the between-tree distributions of these same variables (excluding small larvae) at the Birch Hill and Portage Lake SPA (57 yrs, 63 ft., 113 stems/acre) about 8 miles away. In 1973 and 1974 I measured only cone damage and cone abundance/tree at the Birch Hill SPA.

Each year, I systematically selected 10 sample trees on a transect through the center of the SPAs. I divided the crown of each tree on the basis of crown thirds (upper, middle, lower) and directional quadrants (N, E, S, W) into 12 cells. Within each cell I selected a branch at random for counting larvae and strobili. I sampled early larvae and male strobili during the first week of June, and late larvae and female strobili (cones) in mid July. To estimate the total number of larvae and strobili/tree, I multiplied the mean number of items/branch in each level by the total number of branches in that level and then summed levels.

To detect differences in the densities of larvae and strobili among crown levels and directions, I performed analyses of variances on the 1967 data. All data were transformed to their log counterparts to stabilize variances. Next I pooled the raw data and segregated it by crown levels to compare the observed frequency distributions of insect counts/branch with the calculated negative binomial distribution of same. To relate the distribution of insects among trees to food abundance, I used scatter diagrams and various regression analyses where insects were the dependent variable and food was the independent variable. Similar methods were used to relate the distribution of cone damage among trees to food and insect abundance.

RESULTS

Within Tree Distributions: Early and Late Larvae, Male Strobili and Cones

Differences in the densities of both early larvae and male strobili per branch were significant ($p < 0.01$) among upper and middle and upper and lower crown levels ($Upper_a < Middle_b = Lower_b$)¹ (table 1). In contrast, differences in the densities of late larvae were significant among lower and middle and lower and upper crown levels ($Upper_a \leq Middle_a > Lower_b$). Cone densities were different only between lower and middle levels, and had the same density pattern among levels as late larvae.

¹Variables with the same subletter are not significantly different. ($p \leq 0.05$).

Table 1.--Mean number of *D. disclusa* larvae and reproductive structures per branch by direction in different crown levels at the Birch Hill Seed Production Area in 1967, n= 10 trees

Items per branch	Upper					Middle					Lower				
	N	E	S	W	$\bar{X}$	N	E	S	W	$\bar{X}$	N	E	S	W	$\bar{X}$
Male strobili (MS)	4.5	1.6	3.9	1.5	2.9	29.9	30.3	30.5	36.5	31.8	44.4	26.5	35.9	35.6	36.5
Early-stage larvae (L ₁)	0.8	0.5	0.9	0.7	0.7	4.8	4.1	6.4	6.4	5.4	3.0	2.4	4.3	2.8	3.1
Second-year cones (C)	7.0	6.5	9.1	6.0	7.1	11.2	8.3	15.6	4.6	10.5	4.8	3.4	6.9	3.0	4.5
Late-stage larvae and pupae (L ₂)	1.1	1.3	1.4	0.9	1.2	2.8	0.6	3.1	1.5	2.0	0.5	0.4	0.5	0.5	0.5
Cones attacked by <i>D. disclusa</i> (Y)	3.5	4.3	4.7	2.3	3.7	6.4	4.3	8.1	3.3	5.5	2.1	1.8	2.7	1.9	2.1

Among directional quadrants, there were no significant differences in densities except for cones ($Sa \geq Nab \geq Ebc \geq c$).

Frequency distributions of insect counts/branch conformed to the negative binomial (NB) distribution in all but one instance (large larvae in midcrown) (table 2). The exponent of k value of the NB was smallest for early larvae in the upper level and for late larvae in the lower level. This indicates that the larvae were aggregated most in these levels (Masters 1959).

Table 2.--Statistics relating branch samples of *D. disculsa* in different crown levels to the negative binomial (N.B.) distribution. Chi-square values along with probability (p) of a larger value indicate the degree of correspondence between the observed frequency distribution of larvae/branch and the calculated N.B. distribution of same

SMALL LARVAE			
Sample Statistics	Lower : crown	Middle : crown	Upper : crown
Variance	7.6	40.1	1.7
Mean ¹	3.1	5.4	0.7
Values ²	2.18	0.60	0.28
Chi-square	7.2 (p<.30)	8.0 (p<.50)	5.7 (p<.30)
LARGE LARVAE			
Sample Statistics	Lower : crown	Middle : crown	Upper : crown
Variance	1.0	6.6	2.5
Mean ¹	0.5	2.0	1.2
Values ²	0.26	0.45	0.72
Chi-square	5.5 (p<.20)	19.5 (p<.03)	6.6 (p<.30)

¹n=40 and n=56 for each crown level sample of small larvae and large larvae respectively.

²k values are the exponents of the negative binomial model and were calculated using method 1 or 2 of Anscombe (1949) whichever was appropriate.

Among Tree Distributions: Early and Late Larvae

Among trees, early larvae showed no relationship with cones (C) but did show significant ($p = 0.05$) linear, positive correlation ($r = 0.62$) with male strobili (S).

Late larvae (L2) were only weakly related to C (figure 1). In 1967, for example, L2 reached a peak at medium cone densities. In all other years, however, both Birch Hill and Portage Lake there was no apparent relation between L2 and C. L2 was related to MS in only 2 of 5

sample years as shown in the following regressions:

$$1967 \log(L2) = a + b(C \times MS) + c(MS) + d(C) \text{---} R^2 = 0.74$$

$$1968 L2 = a + b(C \times MS) + c(MS) \text{---} R^2 = 0.81$$

The importance of a variable is indicated by its order in the equation (i.e. $C \times MS > MS > C$). C and MS were not correlated in 4 of 5 years.

Cone Damage in Relation to Food Abundance/Tree

Numbers of cones attacked/tree (Y) exhibited a significant ($p \leq 0.05$) positive, linear correlation with cone abundance (C) in 6 of 9 years (figure 2). In 3 years (1969, 1973, 1974) at Birch Hill, the correlations were clearly positive but only approached significance. The highest correlations occurred (in 1970 at Portage Lake and Birch Hill) when population intensities (numbers relative to food) were highest and second highest respectively. The weakest (nonsignificant) correlations occurred in those years when population intensities were low (1969, 1973, 1974).

Merkel *et al.* (1965) as well as Coulson and Franklin (1968, 1970) also reported positive, linear correlations between Y and C for various species of *Dioryctria* in slash and short leaf pines. Stiell's (1971) data likewise showed a positive, linear correlation between Y and C for *D. disculsa* in red pine plantations.

Consequently, the evidence indicates that Y often shows a positive linear relationship to C: $Y = \pm a + b(C)$. Therefore, percentage cone damage/tree (Y/C) will either increase or decrease to an asymptote (b) depending on the sign of the intercept (a). Theoretically, the sign of a should be negative because Y becomes zero before C does. Therefore, percentage damage should increase slightly with increasing C and eventually approach an asymptote, as Stiell's (1971) data showed for red pine. On the other hand this conflicts with a report by Merkel *et al.* (1965) which showed that percentage damage declined with C. However, the correlations between percentage damage and C in Merkel *et al.* (1965) were significant in only 1 of 3 years. Percentage damage and C, in this study, showed slight negative correlations in 7 of 9 years and slight positive correlations in the other 2 years.

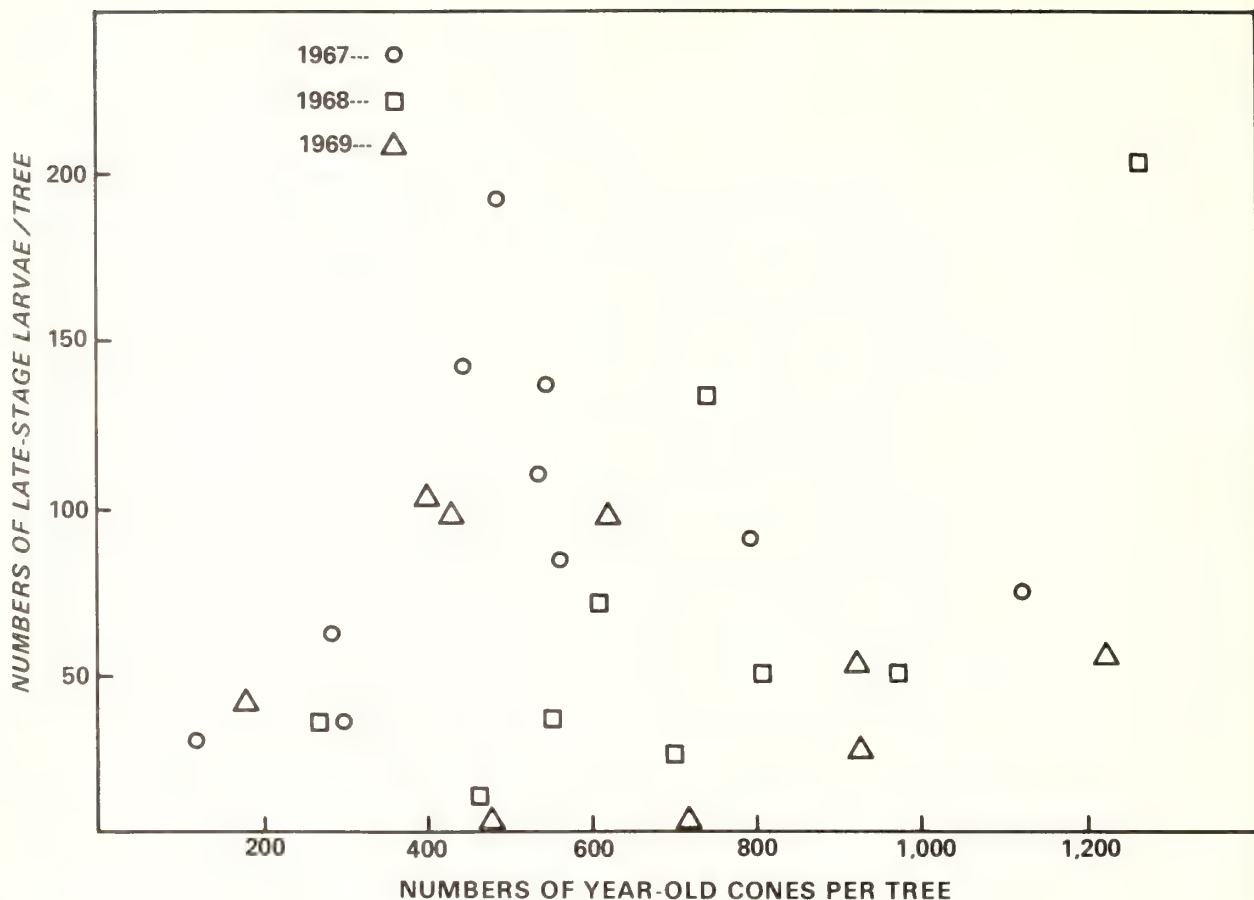


Figure 1.--Numbers of late-stage *Dioryctria disclusa* larvae per tree in relation to numbers of cones per trees in three different years at the Birch Hill seed production area.

However, none were statistically significant. This agrees with the data of Coulson and Franklin (1970). Consequently, the bulk of evidence suggests that percentage damage varies only slightly with C once cone crops exceed the very nominal levels.

C and a logarithmic relationship to MS. MS is probably most important when it is small (<1000/tree).

Because MS was important in explaining the distribution of early and late larvae among trees in some years, I incorporated it along with C in a regression on Y. The best equation took the form: $Y = a + b(C) + c \log(MS)$. However, $\log(MS)$ made a significant contribution to the regression in only 2 of 5 years data (1967, 1969 at Birch Hill). This suggests that Y varies from tree to tree in a linear relationship to

Cone Damage in Relationship to Cone and Early Larval Abundance/Tree

Based upon Holling (1966), Y's increase relative to C's could be either (1) linear up to a plateau or (2) negatively accelerated up to a plateau, if numbers of larvae/tree were constant. Y, however, is not only a function of C but also of L (the number of early larvae/tree). In turn, L appears to be related to MS.

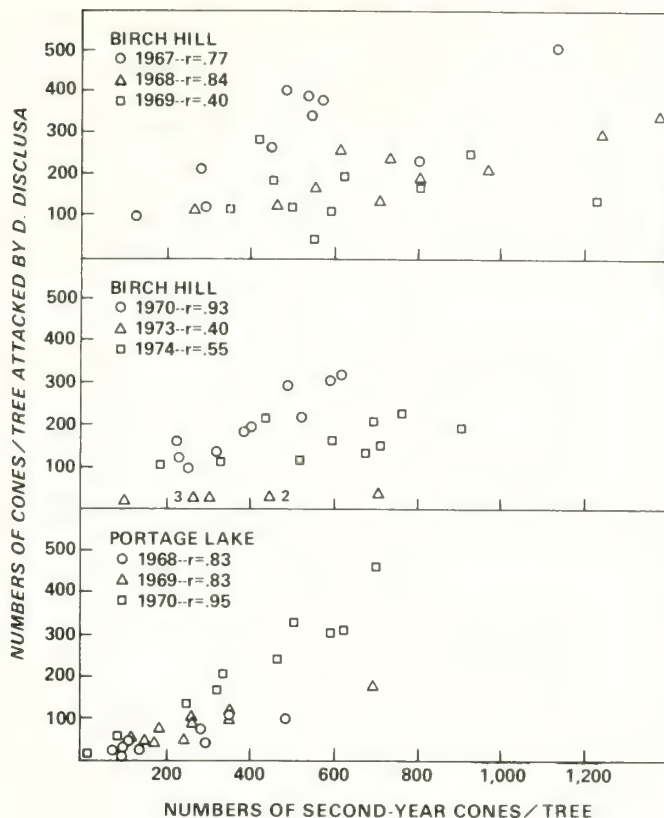


Figure 2.--Numbers of cones per tree attacked by *Dioryctria disclusa* in relationship to total cones available per tree in different years at the Birch Hill and Portage Lake seed production areas.

Watt (1959) formulated a general, mathematical model to characterize the relationship between the number of prey attacked and the densities of both prey and predators. His model can be applied to cones and cone insects as follows:

$$Y = kL(1 - \exp(-aCL^{1-b}))$$

Where Y is the number of attacked cones; C, total cones; and L, total early larvae/tree. k is the maximum number of cones that each larva can attack, and a and b are parameters for the specific case. The model says that Y increases along with C and/or L and eventually plateaus. Increases in C alone cause Y to approach the maximum (the asymptote) defined by kL. Increases in L alone, raise the maximum potential damage (i.e. the asymptote defined by kL) and allows Y to approach the limit determined by C. The parameter, b, has a depressing effect on Y as it increases, and theoretically reflects the interference or competition that results as L increases. For example, as L increases, the probability of each larva

attacking k cones decreases. Watt's model can probably account for some of the observed variation in the simple relationship between Y and C (figure 2). When L is large relative to C (i.e. population intensity is high), for example, Y appears to be a linear function of C because most cones are attacked. When L is small relative to C, Y becomes a function of kL; thus Y shows little relationship to C.

My attempts to fit the 1967 Birch Hill data to Watt's model were not successful, so I modified the model by replacing L^{1-b} with $\exp(-mL)$:

$$Y = kL(1 - \exp(-aC \exp(-mL)))$$

In general, the consequence of such a change will be a more severe depression of the predation potential per predator for any given predator density. It implies greater interference among predators. This model accounted for 84 percent of the variation in Y. Parameters were as follows:

$k=4$, $a=0.00138$, $m=0.00232$. The fact that the modified model fit the data (even though it was only for a single year) suggests that it or the Watt model may be generally applicable to cone predation by insects. This, of course, remains to be tested.

DISCUSSION

Survival of *D. disclusa* appears to be particularly sensitive to the proper spatial and temporal distribution of food. They depend on a fortuitous combination of events: adequate crops of male strobili and year-old cones both in the same tree at the same time. The abundance of male strobili and cones are seldom correlated, however. Thus it is probably common for one food or the other to be a limiting factor. I speculate that highest insect survival and population densities will occur in open grown forests and at forest edges where (1) a greater proportion of trees are capable of producing both types of strobili, and (2) the annual production of strobili/tree is greater and more consistent. Within trees, I speculate the highest insect survival and densities will occur in the midcrown regions where (1) a greater proportion of individual branches will bear both kinds of strobili, and (2) the annual production of strobili is greater and more consistent.

This study revealed that *D. disclusa* and its foods can be sampled simultaneously using the same sources of stratification (levels, directions and trees). Crown levels proved to be an important source of variation for all variables. Directional quadrants were an important source of variation for cones and probably late larvae, but not for male strobili or early larvae.

Insect counts per branch and per tree were overdispersed, not random distributions as evidenced by the fact that the variance of counts tended to increase with insect density. For example, for large larvae per tree, the standard deviation (SD) of counts = $12.1 + .46(\text{mean number larvae/tree})$ where $r^2=.86$. To estimate the number of sample trees (n) needed to achieve a desired level of sampling precision ($(S.E./\text{mean})=k$) in estimating the mean number of late-larvae/tree, the following formula can be used:

$$n = \frac{[12.1 + .46(\text{mean})]^2}{k^2 \text{ mean}^2}$$

When densities are low (about 20/tree), to achieve a population estimate with a standard error (S.E.) roughly 15 percent of the mean ($k=.15$), one would need to sample about 50 trees. To achieve the same precision when densities average about 100/tree, one would need to sample about 15 trees.

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OXFORD: 416.2:453.--145.718. KEY WORDS: negative binomial, sampling, cone damage, male strobili, model.

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MECHANIZED THINNING OF NORTHERN HARDWOOD POLE STANDS } methods and economics

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CONTENTS

The Problem	1
Purpose	1
Methods	1
Results	7
Discussion	13
Conclusions and Recommendations	16
Literature Cited	16

MECHANIZED THINNING OF NORTHERN HARDWOOD POLE STANDS:

METHODS AND ECONOMICS

Frank E. Biltonen, William A. Hillstrom,

Helmuth M. Steinhilb, and Richard M. Godman

THE PROBLEM

There are approximately 32 million acres of northern hardwood forest types in the eastern United States, or 9 percent of the forest land area (Quigley and Morgan 1968). Since the removal of the original northern hardwood forest by commercial clearcutting, most of this area has grown back into second-growth forests that are predominantly stocked with saplings and poles.

Although silviculturists have shown that early and repeated thinnings will increase both the future volume and quality of these dense pole stands, most landowners are discouraged from thinning because there is no immediate monetary return under the old thinning methods. If the thinnings and effective trees could be efficiently and economically harvested, then: (1) landowners would have a monetary incentive to thin; (2) their stands would produce more and better quality timber in the future; and (3) the increasing needs for more hardwood pulp could be met by thinnings and effective trees so that the better trees could be used for lumber and veneer.

Modern logging equipment has made it profitable to harvest smaller volumes of forest products. Smaller, more mobile field chippers make on-site chipping more feasible. Highly maneuverable, articulated feller-bunchers with accumulating shears permit rapid felling and bunching of trees for efficient pickup by grapple skidders. An incentive to utilizing logging residue is the progress made by the Forest Engineering Laboratory, Houghton, Michigan, in removing bark from whole-tree chips. This bark removal process makes it possible to utilize thinnings for producing high-grade pulp (Arola and Erickson 1973, Mattson 1975).

There has been limited research on both individual tree selection and strip thinning using mechanized equipment in natural forests. Zasada and Benzie (1970)

worked with strip thinning and recovery of material, but they used chain saws and choker skidders. Morey (Bryan 1975) used mechanized equipment primarily in individual tree selection. Hooker (1955) did strip thinning without the aid of modern equipment. In the present study, previously tested methods were combined with modern equipment.

PURPOSE

In general, the purpose of this study was to determine the cost of thinning, chipping, and transporting second-growth, northern hardwood pole stands using a completely mechanized system.

The specific objectives were: (1) To determine ways of increasing the productivity of equipment for thinning that is normally used for clearcutting and whole-tree chipping. (2) To evaluate the damage to the residual stand caused by the harvesting equipment. (3) To determine the best thinning method. (4) To determine the cost of mechanized thinning in a northern hardwood stand when the cut material is recovered and utilized.

METHODS

Description of the Stand

A 50-acre, predominantly pole-size stand of mixed species containing a few holdover saw log trees (fig. 1), was selected in the Mishwabic State Forest¹ in Michigan's Upper Peninsula. The soil was a sandy loam. The topography was essentially flat with very minor changes in elevation.

¹Provided by the Michigan Department of Natural Resources on the NW $\frac{1}{4}$ of section 36, T51N, R37W, Ontonagon County. The State of Michigan and the Ahonen Lumber Company of Ironwood cooperated in this study with the North Central Forest Experiment Station.

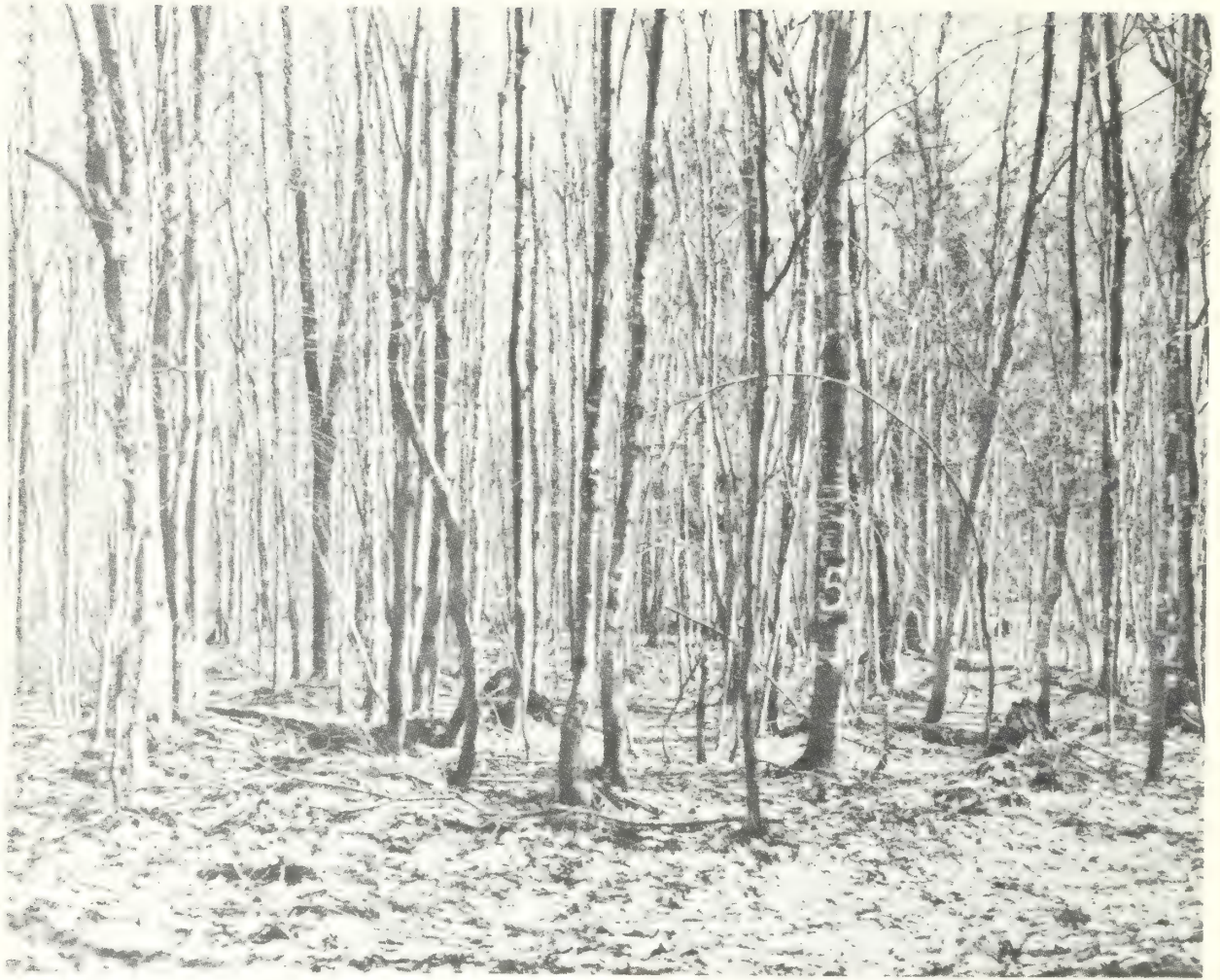


Figure 1.--Typical view of stand as it appeared before thinning.

The stand was bisected into two blocks by a dirt road that extended $\frac{1}{2}$ mile south to a blacktop highway. Each block was 1,650 feet long parallel to the road and 660 feet deep perpendicular to the road. Each of these two blocks was then subdivided into five plots. Each plot was 330 feet wide and 660 feet deep perpendicular to the road and contained 5 acres. A landing was cleared at each end of the area, adjacent to the woods road (fig. 2).

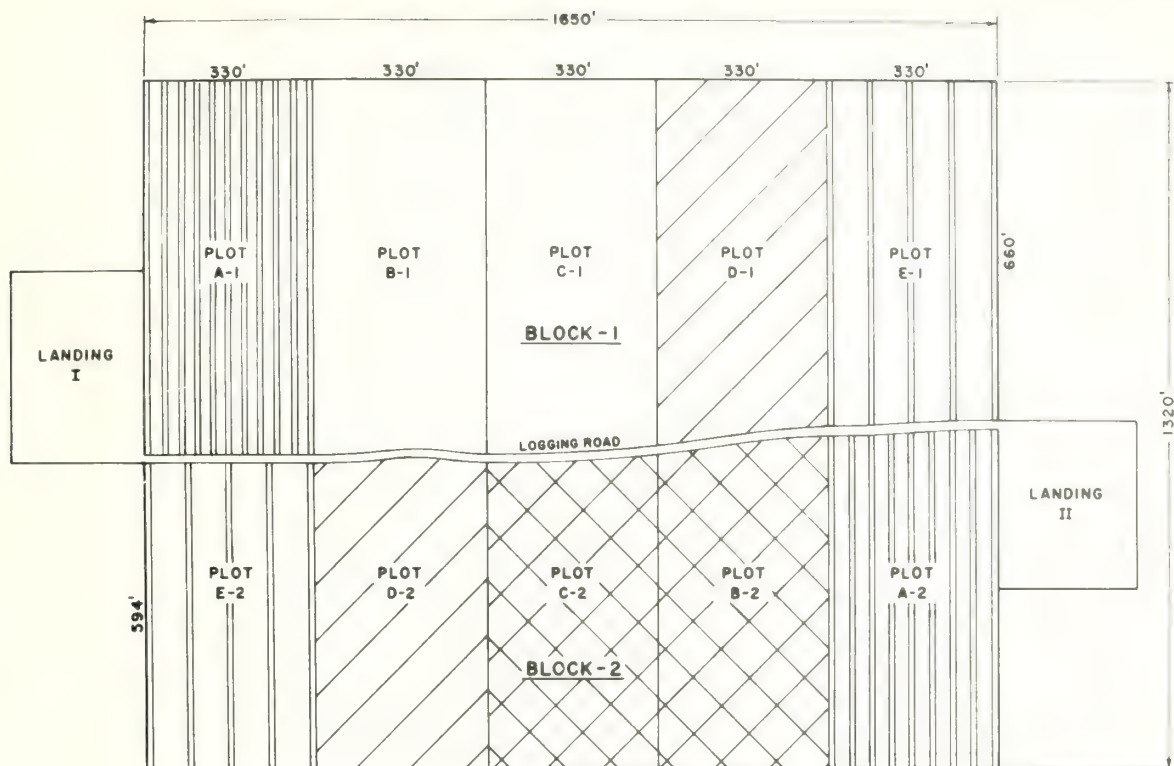
A preliminary survey indicated 13 cords of hardwood pulpwood and 2,700 board feet of small saw logs per acre (table 1). Basal area was about 100 square feet per acre in trees 6 inches d.b.h. and larger. Ring counts made on a few of the larger trees revealed that the virgin hardwood timber had been heavily cut in the late 1920's and early 1930's. Tree diameters ranged from less than 2 inches d.b.h. through 28 inches.

Thinning Treatments

There were five thinning treatments:

- (1) Strip thinning, mechanical felling, and skidding to landing (Plots A-1, A-2).
- (2) Selection thinning², chain saw felling, and no skidding (Plots B-1, C-1).
- (3) Selection thinning, mechanical felling, and skidding (Plots D-1, D-2).
- (4) Strip thinning with selection thinning between strips, mechanical felling, and skidding to landing (Plots E-1, E-2).
- (5) Shelterwood thinning, mechanical felling, and skidding to landing (Plots B-2, C-2). Thinning patterns were apparent both from the air (fig. 3) and on the ground (fig. 4).

²Selection thinning is also referred to as "individual tree selection."



THINNING PATTERNS

SEC. 36, T51N, R37W
ONTONAGON COUNTY, MICHIGAN

LEGEND

PLOT A-1 MECHANICAL STRIP THINNING, SKID TO LANDING
PLOT A-2 MECHANICAL STRIP THINNING, SKID TO LANDING.
PLOT B-1 SELECTION THINNING, CHAIN SAW FELL. TREES NOT SKIDDED.
PLOTS B-2+C-2 SHELTERWOOD THINNING, MECHANICAL FELLING AND SKID.
PLOT C-1 SELECTION THINNING, CHAINSAW FELLING, TREES NOT SKIDDED
PLOTS D-1+D-2 SELECTION THINNING, MECHANICAL FELLING AND SKID.
PLOTS E-1+E-2 STRIP THINNING WITH SELECTION THINNING BETWEEN STRIPS, MECHANICAL FELLING, SKID TO LANDING.

Figure 2.--Layout of plots and thinning patterns, Section 36, T51N, R37W, Ontonagon County, Michigan.

Table 1.--Stock and stand table (per acre) for entire 50 acres before thinning

		Sugar maple			Red maple			Other species ¹			Totals			
D.b.h.	:	Volume			Volume			Volume						
(inches):	Trees	:Volume:(25 percent			:Volume:(55 percent			:Volume:(20 percent			Trees	Basal area	Volume	Volume
	:	: of trees)			: of trees)			: of trees)			:	:	:	:
	No.	Cords	Bd. ft.	No.	Cords	Bd. ft.	No.	Cords	Bd. ft.	No.	Cords	Bd. ft.		
5- 9	35.32	1.65	--	83.72	4.08	--	17.55	1.16	--	136.59	37.49	6.89	--	
10-14	13.17	1.07	295	34.54	3.42	384	21.38	1.68	485	69.09	45.55	6.17	1,164	
15-19	4.46	0.06	707	1.62	0.08	204	3.42	0.29	383	9.50	14.63	0.43	1,294	
20+	0.55	--	125	0.10	--	23	0.32	--	66	0.97	2.29	--	214	
Total	53.50	2.78	1,127	119.98	7.58	611	42.67	3.13	934	216.15	99.96	13.49	2,672	

¹In the western Upper Peninsula of Michigan these second growth hardwood stands are primarily composed of sugar maple (*Acer saccharum*), red maple (*Acer rubrum*), and yellow birch (*Betula alleghaniensis*). There are lesser amounts of black ash (*Fraxinus nigra*), American elm (*Ulmus americana*), black cherry (*Prunus serotina*), hemlock (*Tsuga canadensis*), balsam fir (*Abies balsamea*), and red oak (*Quercus rubra*). The maple, oak, birch, and cherry are valuable commercial species commanding a high price when saw log size.



Figure 3.--Aerial view of thinned site.

Strip thinning.--Plot A-1 was strip-thinned with eleven 10-foot-wide strips located 32 feet apart from center line to center line. All trees within the 10-foot strips were paint-marked for cutting by including all trees within 5 feet of a compass-located center line. No cutting was done on the 22-foot areas between the 10-foot strips. The trees were cut by the feller-buncher, beginning at the end of the strips adjacent to the road. Felled trees were bunched with the butts facing the road to facilitate skidding the full trees to Landing I with the grapple skidder. Because the original basal area of A-1 was 111 square feet per acre in trees 6 inches and over, and because the clearcut strips occupied 33 percent of the area of plot A-1, the basal area of the stand after cutting was therefore assumed

to be 74 square feet per acre in trees 6 inches and larger.

Plot A-2 was very similar to A-1 except that allowances were made for the slight difference in original basal area. A-2 was strip-thinned with nine 10-foot-wide strips located 40 feet apart from center line to center line. All trees within the 10-foot strips were paint-marked for cutting, and no cutting was done on the 30-foot areas between the cut strips. The strips were cut by the feller-buncher beginning at the ends of the strips adjacent to the road. Trees were bunched with butts facing the road and skidded to Landing II with the grapple skidder. The original stand had a basal area of 92 square feet per acre in



Figure 4.--Ground view of thinned site.

trees 6 inches d.b.h. and larger. The clear-cut strips occupied 27.27 percent of the area of plot A-2, leaving a basal area after cutting of 67 square feet per acre.

Selection thinning.--Plots B-1 and C-1 were marked for selection thinning by painting "leave" trees to a residual basal area of 73 square feet per acre. The trees (including saplings) were felled by chain saw and were not removed from the area. This practice is similar to a commonly used timber stand improvement (tsi) procedure except that in tsi work trees are marked to fall, leaving most saplings uncut. During marking, plots were subdivided into marking units a chain square to assure uniformity in stand conditions and residual basal areas.

Selection thinning (Mechanical felling).--Plots D-1 and D-2 were marked for

selection thinning by painting the residual trees to a basal area of 67 square feet per acre in trees 6 inches d.b.h. and larger. Trees to be cut were felled with the feller-buncher, placed with the butts facing the road, and moved to landings with the grapple skidder. Plot D-1 was skidded to Landing II and D-2 to Landing I.

Strip-thinning with selection between strips.--Plots E-1 and E-2 were strip-thinned with five 10-foot-wide cut strips. All trees within the 10-foot strips were paint-marked for cutting, and "leave" trees in the 70-foot areas between strips were paint-marked and tallied to 0.1-inch d.b.h. for a selection thinning. The residual basal area was 57 square feet per acre in trees 6 inches d.b.h. and larger. The trees were felled with the feller-buncher, placed in piles, and skidded to the landings by

the grapple skidder. Trees from E-1 went to Landing II and from E-2 to Landing I.

Shelterwood thinning.--In Plots B-2 and C-2 "leave" trees were paint-marked for a two-cut shelterwood, leaving a residual stand with a crown cover of approximately 70 percent or 30,000 square feet per acre, and a basal area of 59 square feet per acre. Trees were cut by the feller-buncher and skidded to Landing II by the grapple skidder. The shelterwood cut was included in the study because it is a way of encouraging regeneration while the residual trees are increasing in size (Godman and Tubbs 1973).

Damage Survey

The extent of damage to the residual stand was determined in two ways: (1) by running a transect diagonally across each plot and describing the location and severity of each injury on damaged trees on the transect; and (2) sampling for presence or absence of injury during residual stand tallies of each plot.

Equipment and Manpower

The three major pieces of harvest equipment used in this operation were: a

Rome Grapple Shear³ with accumulator top clamp mounted on a John Deere 544 Loader, a Clark Ranger 667 GS Grapple Skidder, and the Trelan D-60 Whole-Tree Chipper (fig. 5).

For transporting the chips to the mill, two truck-tractor units were used in combination with four chip vans. Auxiliary equipment consisted of one Barko Loader to feed the chipper, one maintenance truck, one fuel truck, one chain saw, and a landing truck for spotting vans. Five men were required for the operation--four were equipment operators who alternated every 3 or 4 hours between machines to reduce operator fatigue. Table 2 lists the equipment including the purchase price and operating costs for each machine.

Time measurement and data collection.--All operations during the study were observed and total time and delay data were recorded for determining performance and operating costs. These data can be used for predicting results of similar operations in other stands, and for computer simulation studies (Bradley *et al.* 1976). Three stopwatches were used with a commercial timing board

³Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.



Figure 5.--Major equipment used: (Left) John Deere 544 Feller-Buncher with Rome Accumulator Shear; (Center) Clark Ranger 667 Grapple Skidder; and (Right) Trelan D-60 Whole-Tree Chipper.

Table 2.--Itemized equipment cost
(In dollars)

Machine	: Initial :Cost/hour (without labor)		
	: cost :	Fixed	: Operating
1 Clark Ranger 667 Grapple Skidder	\$ 38,943	\$ 6.72	\$ 6.15
1 Treilan Chipper	34,000	5.86	6.75
1 Barko Loader	17,122	2.95	2.39
1 John Deere 544 with Rome Shear	39,900	6.88	7.55
Subtotal	\$129,965	\$22.41	\$22.84
5 Chip vans	\$25,980	\$ 4.51	\$ 8.26
2 Truck tractor units	56,100	10.72	20.62
Subtotal	\$82,080	\$15.23	\$28.88
1 Maintenance and fuel truck	\$3,990	\$0.58	\$0.42
1 Landing truck	2,500	.46	.85
1 Chain saw	280	.24	.70
Subtotal	\$6,770	\$1.28	\$1.97
Total	\$218,815	\$38.92	\$53.69

for continuous timing of events. A fourth independent watch was used to record delays. All distances were estimated.

RESULTS

System Productivity

Feller-buncher travel times, travel distances, shear and bunch times, and delays that occurred during each felling cycle were recorded. Because the feller-buncher had an accumulating head, a felling cycle started with the shearing of the first tree and continued until the accumulated bunch was laid down for the grapple skidder.

For convenience, the skidding data were recorded at two locations--in the woods and at the landing. Data for each turn included pick up time, number of trees, average d.b.h. (estimated), skidding distance, drop time, delays, and turnaround time.

Data recorded for each chipping cycle consisted of number of stems, average estimated d.b.h., delays, and total cycle time. A chipping cycle began with each grapple load.

All equipment data sheets recorded the operator's name, weather conditions, van load number, topography, soil conditions, brush conditions, and equipment used.

Separate data sheets were kept on the transportation of chips. These indicated the truck departure and arrival times, plot number, miles traveled, and the empty and full weights.

Upon completion of the study, all data were keypunched and computer programs written to compute costs, rates, and volumes.

The timing of machine operations resulted in construction of table 3, which lists the percent of productive time and percent of various delays for each machine used in thinning.

Table 3.--Productive machine time and classification of delays
(In percent)

Time category	: Feller- : buncher :	: Skidder :	: Chipper and : loader
Productive time	67	62	49
Delays			
Lunch breaks	13	10	--
Wait for skidder	3	--	6
Miscellaneous	3	--	2
Discussion	3	1	--
Repair and maintenance	5	9	15
Help others	5	--	--
Change plots	1	--	--
Change vans	--	11	22
Wait for chipper	--	5	--
Bunching	--	2	--
Cut and stack saw logs	--	--	4
Clear branches	--	--	1
Change landings	--	--	1
Total time scheduled	100	100	100

Feller-buncher felling.--The feller-buncher (with accumulator shear) used in this study operated at an average felling rate of 85 stems per hour including delays (table 4). Differences in felling rates between treatments were not obvious because the treatment plots were felled by different operators who varied greatly in efficiency.

Table 4.--Feller-buncher¹ operating rates by treatment
(In numbers)

Treatment	: Felling: : cycles	: Stems: per cycle	: Stems per: skidder bunch	: Stems per hour Without: delays	: Actual
Strip	672	2.90	9.1	139.2	88.8
Shelterwood	858	2.90	11.1	133.8	87.0
Selective	709	2.95	11.2	137.4	80.0
Strip with selective	933	2.70	10.7	128.4	85.2

¹John Deere 544 with Rome Shear.

Chain saw felling.--For comparison with feller-buncher plots, two 5-acre plots were selectively thinned with a chain saw by an experienced Michigan Department of Natural Resources (DNR) employee. The feller was instructed to fell the trees all in the same direction so they could be easily skidded to a landing and chipped or cut for saw logs. But he could not spend the time to carefully fell the closely spaced trees in the proper spot to facilitate skidding, and still be highly productive in

felling. The attempt at skidding ended in failure. The felled trees, severely criss-crossed and entangled, were nearly impossible to skid with a choker skidder (fig. 6).

Total chain saw felling time was 2.24 minutes per tree or about 27 trees per hour (table 5). This included time to cut many saplings that were not counted in the "number of trees" column. The productivity of chain saw felling per man was more than 1.4 acres per 8-hour day.



Figure 6.--Results of chain saw felling.

Table 5.--Time study data from chain saw felling
(In minutes)

Plot and No. of trees ¹	Observation: : and : : walking :	Brush	Felling	Delay	Total
B-1 (739)	608.54	33.97	431.4	326.21	1,796
C-1 (886)	883.72	35.49	461.90	461.27	1,849
Total	1,625	1,492.26	69.46	893.30	787.48
Average per tree	0.92	0.04	0.55	0.48	2.24

¹Average d.b.h. for both plots was 7.1 inches.

Land treated (acres)	10.89
Trees per acre felled (no.)	149.2
Total trees felled (no.)	1,625
Average felling time per tree (min.)	2.24
Average felling time per acre (hr.)	5.57

Cost per acre

Labor (sawyer)	\$22.28
Surveying and marking	5.75
Paint	.25
Chain saw and fuel cost	5.24
	\$33.52
per acre	

Skidding.--The skidder was most productive in the selectively thinned plot, equally productive in shelterwood and strip-with-selection thinning, and least productive in the strip thinning (table 6). The average weight per skid for all thinning treatments was 2.5 tons. Strip thinning was low in productivity because there were not enough trees within the operating limits of the machine on the 10-foot strips to make full-size bunches.

Chipping.--Without delays, the chipper produced 35 tons per hour; with all delays included, production dropped to about 17 tons per hour (table 7).

Material Removed and Costs

Material removed.--A total of 1,769 tons of chips (74 vans of 24-ton capacity) and 9,640 board feet of saw logs were removed from the study site in 22 partial days of operation. Total weight of both chips and saw logs was 1,829 tons (table 8).

Production costs.--Production costs are those incurred directly in cutting and removing the trees--felling, skidding, and transport. All production costs discussed include delays, avoidable and unavoidable, and should be regarded as conservative because proficiency will improve as loggers gain experience. Although these production costs are not excessive, nonproduction costs (tree marking, site preparation, and stumpage) are not included here because of their nature and variability. They are discussed

Table 6.--Grapple skidder¹ operating rates by treatment

Treatment	: Skids : : : : No.	: Average distance : : per skid : : feet	: Average : : stems : : No.	: Average : : weight per : : skid : : Tons	: Total time : : per skid : : Minutes	: Without delay : : Actual
Strip	214	517	638	9.1	1.67	4.5
Shelterwood	200	1,368	622	11.1	2.43	5.0
Selective	173	1,186	711	11.2	2.61	4.7
Strip with selective	219	518	625	10.7	2.42	4.5

¹Clark Ranger 667.

Table 7.--Chipper¹ operating rates for entire study

Vans	: Stems : : : : No.	: Chipping : : cycles : : cycles	: Stems : : per : : per	: Stems : : per : : per	: Minutes per van : : Without : : Actual	: Tons per hour : : Without : : Actual
73.75	8,570	5,336	1.6	116.2	41.35	83.82
						34.82
						17.18

¹Treilan.

Table 8.--Material removed

Treatment and size (acres)	Chips : removed:	Saw logs : removed:	Total : removed:	Tons/acre	Stems/acre
	Tons	Bd. ft.	Tons		
Strip (10.5)	342	2,760	359	34.2	186.2
Shelterwood (9.61)	470	2,670	486	50.6	255.0
Selective (9.5)	444	1,380	453	47.7	219.2
Strip with selective (9.5)	513	2,830	531	55.9	263.9
Total	1,769	9,640	1,829		
Average				46.8	230.0

later. Felling, skidding, chipping, and transport account for over 80 percent of the \$8.78 per ton required to produce the chips (table 9). Transport costs alone were \$2.61 per ton or 30 percent of the total.

Table 9.--Breakdown of costs¹

Item	Equipment	Labor	Total	Percent of total
- - Dollars/ton - - -				
Feller-buncher	\$1.13	\$0.68	\$1.81	21
Skidder	0.94	.68	1.62	19
Chipper	1.29	.68	1.97	22
Chain saw	.03	.27	0.30	3
Maintenance and fuel truck	.06	.41	.47	5
Chip van	.48	.31	.79	9
Highway truck	1.40	.31	1.71	20
Landing truck	.04	.07	.11	1
Total	\$5.37	\$3.41	\$8.78	100

¹Average of all thinning treatments on 40 acres.

Break-even analysis.--A "break-even" chart was constructed from careful analysis of machine costs and rates (fig. 7). The fixed cost of thinning per day was \$593.00. This included labor, depreciation, interest, insurance, taxes, licenses, and other miscellaneous fixed costs. For the break-even analysis, labor (\$35.25 per hour⁴) was considered as a fixed cost because it was being charged whether or not the machines were operated. An additional \$36.77 per hour is necessary to operate the equipment. Therefore, \$887.00 of revenue must be realized for an 8-hour operating day in order to break even. When the system produced at the rate of 13 tons per hour, which was the average hourly rate for the lowest daily production during the study, a break-even point was achieved after 5 hours of production (fig. 7). This calculation is

⁴Labor costs calculated for five men totals \$35.25 per hour: \$4.50 per hour for four men and \$5.50 per hour for one man, plus 50 percent of the hourly total for overhead.

based on revenue of \$11.85 per green ton delivered to the mill. When thinning produced 26 tons per hour, the average hourly rate for the best daily production during the study, it took slightly over 2 hours to break even.

Figure 8 displays a more realistic picture entailing both profit and loss based on the average rate of production for the duration of the study. Using the same logic as for figure 7, it took just over 3- $\frac{1}{2}$ hours of producing at the average rate of 17 tons per hour to reach the break-even point.

Costs by treatment.--Strip thinning--the most costly--was 40 percent more expensive than the shelterwood cut--the least costly (table 10). But for all practical purposes, differences in costs cannot be considered significant because factors that affected productivity (such as weather, operator ability, skidding distances, and unavoidable delays) were not constant from treatment to treatment. For example, among all treatments, feller-buncher operators varied as much as 25 percent in their productivity, other factors being equal.

Nonproduction costs.--Depending on the type of thinning, marking will cost from 5 cents per ton for strip thinning to 15 cents per ton for selective thinning.

Site preparation costs depend largely upon the size of the area to be logged. In this study an existing road was improved and two landings were cleared for only 40 acres of thinning. Therefore, for this study, site preparation and road improvements cost \$1.00 per ton; it would have been possible to thin a much larger area utilizing the same roads and landings so that costs would have been less than 25 cents per ton. In addition, improved roads will service future logging operations, making site preparation costs negligible.

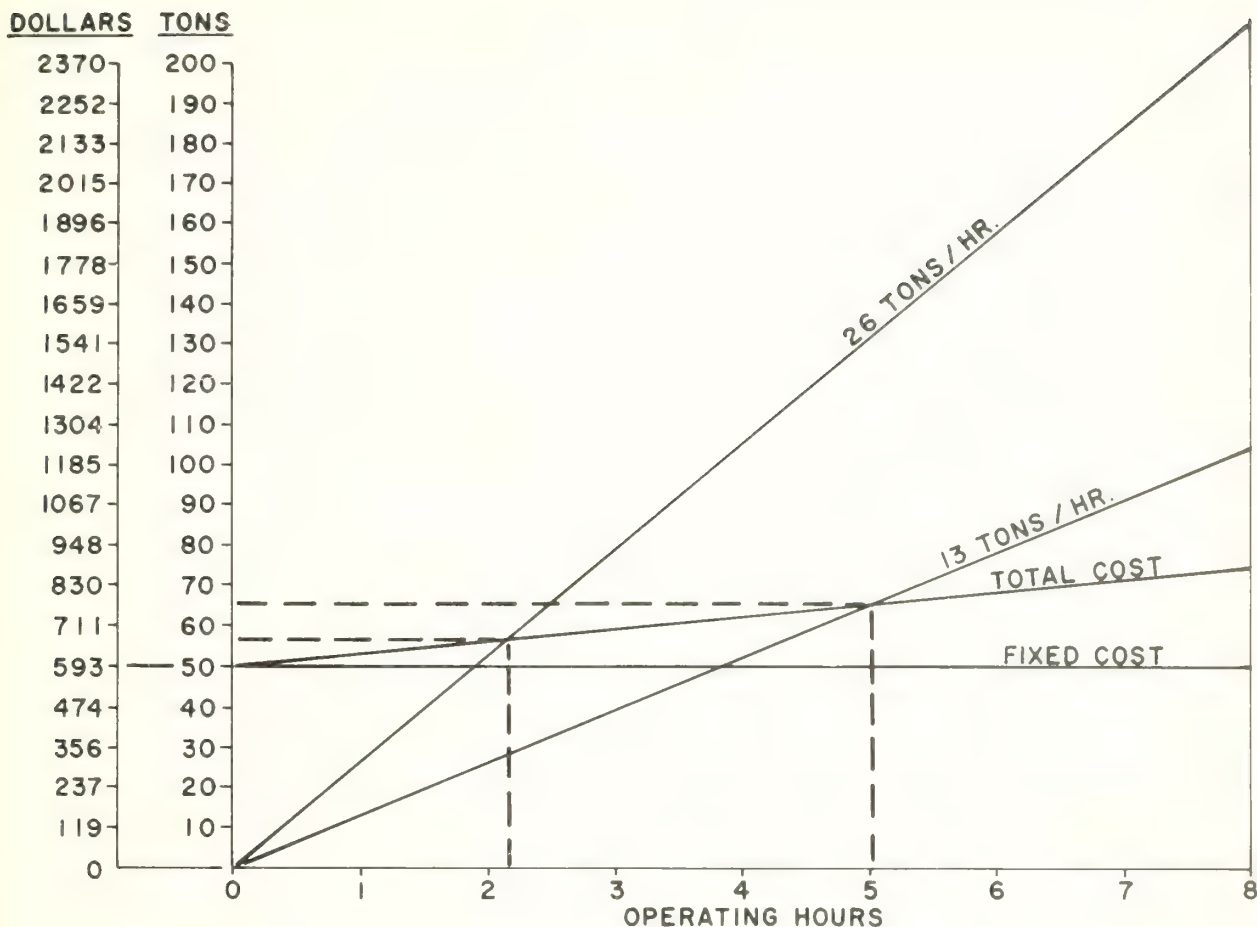


Figure 7.--Maximum and minimum break-even points for entire thinning.

Stumpage costs were ignored in this study because this stand was thinned as if it were being done by the Michigan Department of Natural Resources (DNR). Thinning in this manner by the DNR usually costs the State \$25.00 per acre if the material is chain saw felled and left to decay.

If mechanized thinning should become a normal harvesting operation, cost calculations may have to include stumpage allowances. Table 11 illustrates the possibility of cost-benefit when applying the strip-with-selection thinning, including all costs. Based on the actual amount of product removed by this method (55.9 tons), a profit of \$125.00 per acre was obtained.

Damage to Residual Stand

Kinds of injuries.--All plots harvested by the feller-buncher and skidder had significantly more bole and root injuries than the chain saw felled trees (table 12).

Crown injuries were minor (they were most prevalent in stands thinned by chain saw) and consisted primarily of small and lower limb breakage that should not adversely influence crown development.

Bole injuries were the most common; an average of from 6 trees per acre in chain saw felling to 63 trees per acre in strip thinning had bole injuries. Fewer trees were injured (22 per acre) by the feller-buncher and grapple skidder during selection thinning between strips (table 13), but there were more injuries per tree (3.0), injuries were more severe, and they were higher up the bole than in other treatments.

Root injuries ranged from an average of 6 trees per acre in the shelterwood cutting to 39 trees per acre in strip cutting. Unexpectedly, the selection between strips had more major root injuries (67 percent were major) than other mechanized methods.

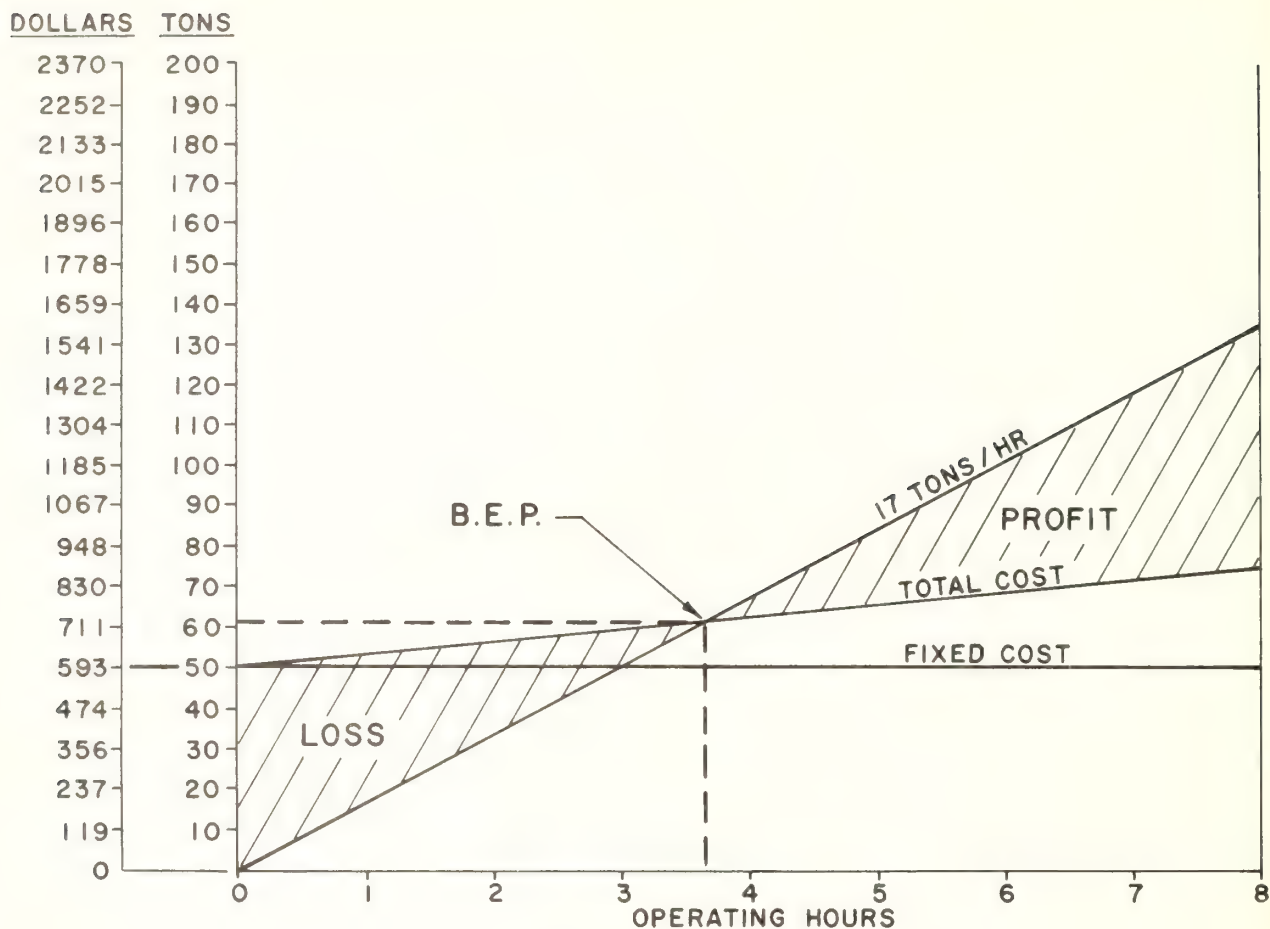


Figure 8.--Profit and loss based on the mean productivity for entire thinning.

Table 10.--Cost of thinning treatments
(In dollars/ton)

Treatment	Equipment	Labor	Total
Strip	\$6.38	\$4.49	\$10.87
Shelterwood	5.04	2.74	7.78
Selective	5.12	3.47	8.59
Strip with selective	5.21	3.27	8.48
Average	\$5.37	\$3.41	\$ 8.78

However, there was no consistent relation between root injuries and bole injuries on the same trees. Although root injuries were more frequent in the strip thinnings, they were just as severe far from the main haul road as close to it.

Strip thinning injuries.--The thinning patterns were a major factor in the frequency

Table 11.--Projected return from strip thinning with selection between strips

Cost		Delivered return	
Dollars/ton			
Stumpage	\$0.50	Revenue/green ton	\$11.85
Marking	.10	Delivered cost/ton	9.60
Roads and landings	.22	Profit/green ton	\$ 2.25 ¹
Harvesting	6.18		
Transport	2.60		
Total	\$9.60/green ton		

¹Based on 55.9 tons removed per acre, a profit of \$125.78 per acre may be realized.

Table 12.--Frequency of tree injuries by cutting method and location on tree

Marking and harvesting method	:Residual:		Trees with one or more injuries			
	: trees : :per acre:	: No. :	Per : acre :	: Proportion with injuries to:		
				Bole	Roots	Crown
	No.	No.	Percent	Percent	Percent	Percent
Chain saw						
Selection	155	16	10	39	0	58
Mechanized equipment						
Shelterwood	109	23	21	99	28	14
Selection	137	46	34	77	30	36
Selection between strips	156	31	20	70	45	30
Strips ¹	350	86	25	73	45	16

¹Applies to area between strips.

Table 13.--Severity of injuries by cutting method and location on tree

Marking and harvesting method	: Bole injuries :		: Root injuries :			
	Trees	:	Trees	:		
	per acre:	Major ¹	Minor:	per acre:	Major:	Minor:
	No.	Percent	No.	Percent		
Chain saw						
Selection	6	0	100	0	--	--
Mechanized equipment						
Shelterwood	23	29	71	6	50	50
Selection	35	9	91	14	50	50
Selection between strips	22	60	40	14	67	33
Strips ²	63	40	60	39	33	67

¹"Major" injuries had 50 square inches or more of stem or root cambium exposed. "Minor" injuries had less than 50 square inches of stem or root cambium exposed.

²Applies to area between strips.

of damage to residual trees. In the strip thinnings, which had the greatest number of injured trees per acre, the average spacing of trees was 11.2 feet. All of the trees cut from the strip had to be placed to the right of the operator into the uncut stand. This frequently involved repeated placement of small bunches and many reverse movements by the feller-buncher with trees in the accumulator head. Consequently, the repeated movements and placement of cut trees into closely spaced standing trees caused an increase in bole and root injuries. In conjunction with this, the productivity of felling and skidding equipment was the lowest of the several cutting methods.

Selection thinning (mechanical) injuries.--Selection cutting had the second highest injury rate. Because the feller-buncher meandered randomly within the plot, more trees were injured but most injuries were classified as minor.

Strip-thinning-with-selection-between-strips injuries.--This method resulted in the greatest percent of major bole and root injuries of all the mechanized thinning treatments because of the concentrated logging activity along the edge of the strips.

Contributing to this was the relatively narrow spacing between trees in this plot (averaging 16.7 feet).

Mechanical thinning injuries compared to conventional harvesting injuries.--Injuries were more common than reported for conventional methods of harvesting (Benzie 1959, Engle 1947, Meyer *et al.* 1966). Factors contributing to the variation in injuries were differences in spacing within a plot, the difference between equipment operators, and weather conditions.

Although injuries occurred more frequently than in previously reported studies, most are expected to be relatively minor. Many of the damaged trees can be removed in future thinnings and, according to older studies, before significant volume or value losses occur in these young, vigorous stands (Hesterberg 1957, Ohman 1970).

DISCUSSION

System Productivity

Balance of equipment.--In order to optimize the efficiency of a thinning system,

the operating rate of each major element of the system should be approximately equal (table 14). In the present study, the balance was generally good with the exception of the chipper, which had a production capability from 20 to 30 percent greater than the feller-buncher and skidder.

Felling.--When selecting a shear to operate in hardwoods, primary consideration must be given to maximum shearing force (approximately 6,600 pounds per inch width of cut when using a 3/4-inch blade in hard maple) (Arola 1972). Therefore, a 10-inch maple may take up to 66,000 pounds of shearing force to fell. It is also necessary to have a shear with accumulating capabilities in order to collect as many small stems as possible in the felling head before bunching. Figure 9 illustrates the difference in production volume between a single tree shear and an accumulator shear (Rome Industries 1972). The shear used in the present study had both capabilities.

Skidding.--The grapple skidder was an acceptable machine for this thinning operation. However, the feller-buncher operator must be familiar with the maximum size load the grapple skidder can handle in order to optimize the latter's productivity. As mentioned, too narrow a strip prevents the grapple skidder from attaining maximum productivity.

Chipping.--The chipper used on this operation was an efficient machine, however, a separate loader must be located adjacent to the chipper and placed so that the skidder can only drop its load at the feed end of the chipper. This was a major cause of skidder delays because the chipper must chip everything in the drop zone before the skidder can deposit another load.

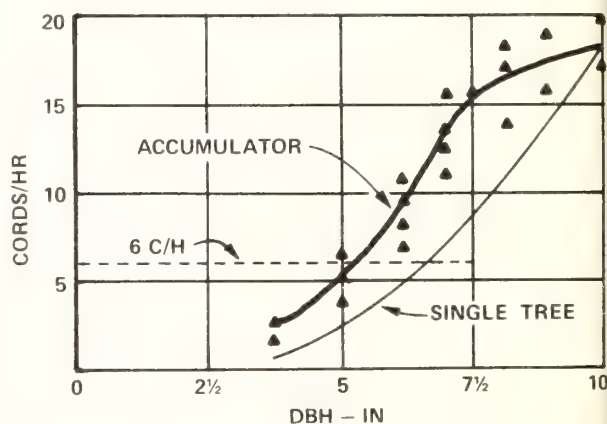
Advantages and Disadvantages of Thinning Treatments

Selection thinning.--Silviculturally, selection thinning is superior to strip thinning but is more difficult to mechanize because:

1. The feller-buncher and skidder must both operate in the stand, creating a higher risk possibility for injury to the remaining trees.
2. A good felling and removal system is difficult to coordinate because both machines tend to interfere with one another--bunches felled in uncut areas must be removed before felling can be continued.
3. Skidder operators are often not experienced enough to decide the least damaging route out of the woods each time they pick up a load.

COMPARISON OF SHEAR PRODUCTIVITY

(ACCUMULATOR VS SINGLE TREE)



SOURCE: DEERE & CO.

Figure 9.--Production curves indicating the difference between a single tree feller-buncher and a feller-buncher with an accumulator shear.

Table 14.--Productivity of various operations by thinning treatment, with and without delays

Treatment		Feller-buncher		Skidder		Chipper	
		Stems/hr	Tons/hr	Stems/hr	Tons/hr	Stems/hr	Tons/hr
Strip	(Without delays)	139.7	24.0	121.3	22.3	154.4	29.4
	(Actual)	89.6	16.4	87.4	16.0	93.7	18.2
Shelterwood	(Without delays)	133.8	25.0	133.2	28.8	185.2	36.1
	(Actual)	87.4	17.2	71.2	15.9	77.1	15.0
Selective	(Without delays)	137.2	29.7	143.0	36.9	174.9	37.6
	(Actual)	79.7	17.3	61.8	16.1	75.7	16.3
Strip with selective	(Without delays)	129.1	26.7	143.4	31.3	170.6	37.2
	(Actual)	85.7	21.5	75.2	17.0	88.2	19.3
Average (weighted)	(Without delays)	133.3	27.2	135.0	31.3	172.3	34.8
	(Actual)	88.8	17.5	72.5	16.8	82.2	17.2

Strip thinning.--Strip thinning is easy to mechanize but silviculturally less satisfactory because there is no possibility of choosing between individual trees. All trees within the strip should be cut. In addition, the 10-foot-wide strips were not adequate to maximize production as previously discussed. Residual stand damage was high because the feller-buncher must always place the cut material into the uncut stand.

Strip thinning with selection--the best method.--Strip thinning with individual tree selection between strips was a good compromise because it was reasonably productive and was acceptable silviculturally. It was also preferred by the equipment operators and adopted by the logger as the system to use on his own woodlands.

Figure 10 shows why the strip with selection system was preferred. Initially, the feller-buncher starts cutting a 10-foot-wide strip, laying all bunches to the right. As soon as the end of the strip (660 feet in this case) is reached, the operator would go to his left and begin selectively thinning the between-strip space

up to where the next strip will be (70 feet). The trees from the selective area would be bunched in the previously cut strip, thereby minimizing damage and also concentrating all of the cut material either in the cut strip or adjacent to it. After the operator has finished the selective cutting, he is back at his starting point and has one cut strip and a 70-foot-wide band of selectively thinned area. He then moves 70 feet to the left and begins a new strip, again laying bunches to the right and into the thinned area he just finished cutting. As he progresses in this manner to his left, he can cut many acres of material and never interfere with the skidder. With all the material being concentrated on a strip, the skidder operator, experienced or not, can easily follow the cutting pattern without having to make any skidding route decisions.

Other Considerations

Landings.--The in-woods landing only occupied $\frac{1}{2}$ acre but was adequate to efficiently service the operation (fig. 10).

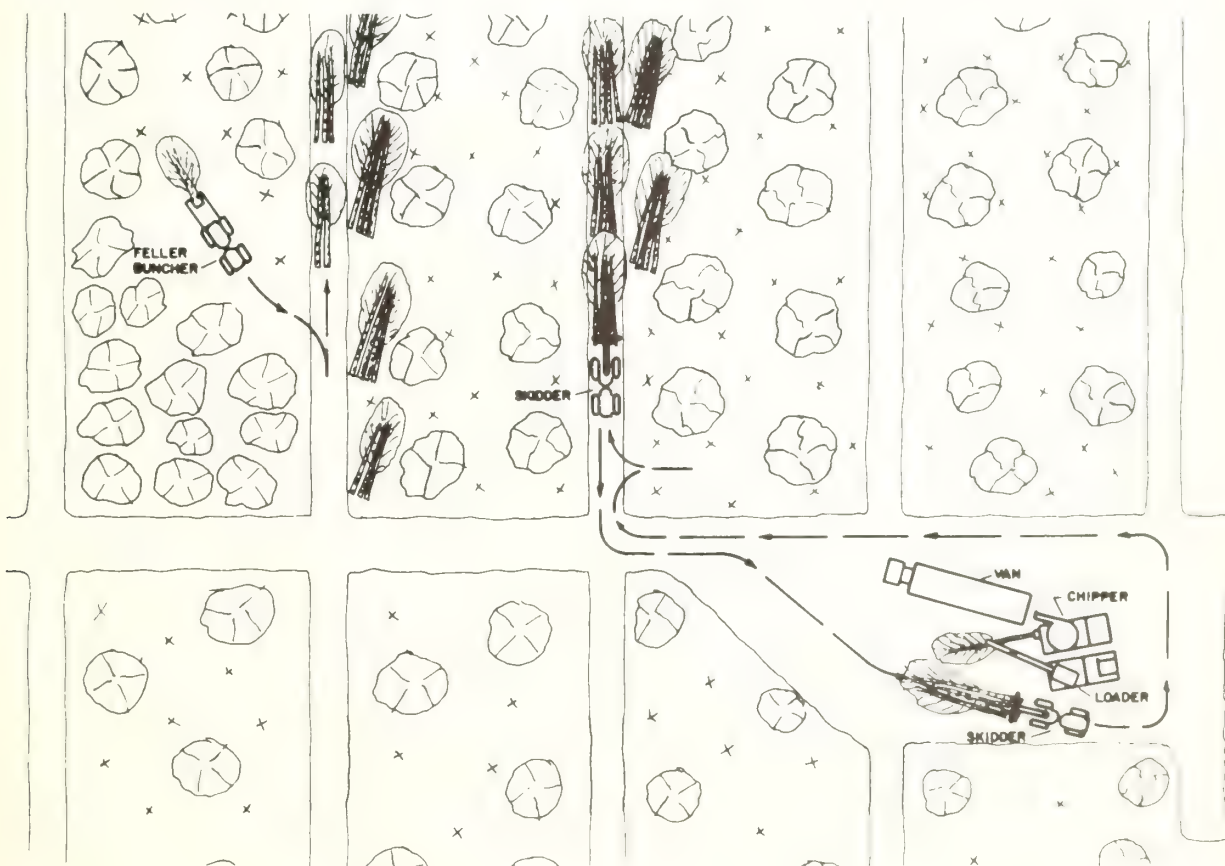


Figure 10.--Strip with selective thinning system.

Construction of this landing took approximately $\frac{1}{2}$ day and began with the feller-buncher cutting and decking the entire area without intermediate handling by the skidder. This allowed the dozer to stump and level the area immediately after felling. The chipper was then placed next to the decked material (about one van load), which it started to chip while the feller-buncher got a head start on the rest of the operation. The landing was also designed with a small spur road on one end that was used as a van turnaround and van storage area.

Effects of weather.--This study began in the first days of November 1974 and ended 1 month later during the transition period between fall and winter. All types of weather were encountered--dry, rain and snow mixed, and heavy snow. Temperatures ranged from 75° F down to 10° F. The greatest problem associated with weather was chipper knife maintenance. Skidding during wet, snowy, and freezing conditions caused an accumulation of dirt and grit on the branches that dulled the chipper knives. They consequently had to be changed for every van load of chips. As soon as the ground became frozen and snow covered, the chipper knives lasted about 10 times longer. In winter there is greater ease of movement on the frozen ground and possibly less damage to the forest floor and root systems of the residual stand.

CONCLUSIONS AND RECOMMENDATIONS

1. Strip thinning with tree selection within the "leave" strip had some drawbacks, but it was the best of the treatments.

2. It is possible to realize a profit from mechanized thinning in pole stands but it will be less than from clearcutting and chipping whole trees.

3. Because operators have a large investment in equipment, mechanized thinning might be achieved by subsidizing any equipment owner willing to try thinning. A portion of the money now being spent on other thinning methods could be paid directly to him. The amount might be enough to encourage a logger to try it and perhaps, with experience, the need for a subsidy would diminish. Because we need to develop thinning specialists now, we hope this study will encourage capable operators to undertake thinning, and encourage others to support these operators until they become self-sufficient.

4. Further tests of these thinning treatments should be made on larger tracts giving the equipment operator freedom to operate within the constraints of the system and not be burdened with continual observation of every move. Larger areas will permit experimentation with tree marking, methods, strip widths, and landing sizes and locations. Tree marking could be minimized to reduce costs. A properly trained feller-buncher might be able to do an adequate thinning job with little or no tree marking.

5. Wider strips, resulting in greater productivity, could also reduce tree damage on strip edges, or damaged trees could be removed right after thinning. A study of the most economical landing sizes, road types, and locations of each would be beneficial.

6. Different equipment combinations might be more productive.

7. Computer simulation of mechanized thinning will reduce the cost of further research by solving problems that would otherwise have to be solved by field testing. Basic data collected in this study will be used as input in the GPSS⁵ Whole-Tree Field Chipping Simulation System.

⁵The GPSS (*General Purpose Simulation System*) is an IBM computer language for simulating discrete systems (Bradley et al. 1976).

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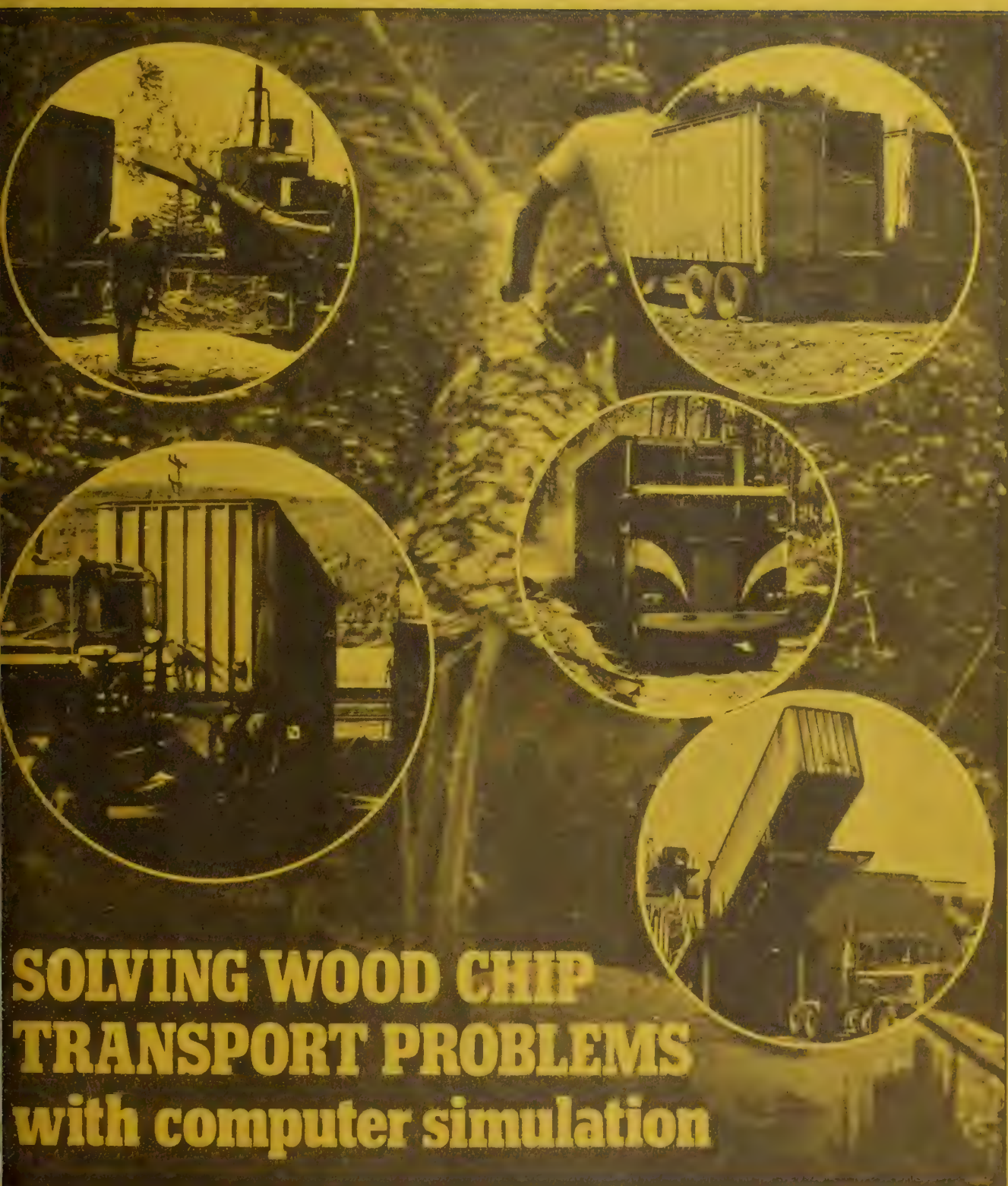
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SOLVING WOOD CHIP TRANSPORT PROBLEMS with computer simulation

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CONTENTS

The Advantages of Simulation	1
The Chip Transport Simulator	2
Example Number 1--A Case Study	4
Example Number 2--A Hypothetical Case	5
Appendix--Actual Simulator Reports of the Chip Trucking Operation Used in the Example	7

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SOLVING WOOD CHIP TRANSPORT PROBLEMS

WITH COMPUTER SIMULATION

Dennis P. Bradley and Sharon A. Winsauer

Efficient chip transport is the key to marketing wood chips produced in the field. Yet efficiency is an elusive objective because of constantly changing harvesting location and other factors. Ideally, one should alter the amount and organization of transport equipment as chipping rate, distance to mill, mill quota, or other factors change. But the high cost of trucks and vans requires that most loggers decide upon a combination of men and machines that best fits their average conditions. Although contract haulers or truck rental and leasing arrangements are often available to help adjust to unforeseen needs, the problem of "how much" still remains. The "seat-of-the-pants" calculations and actual trials currently employed are always confusing, and many good alternatives are not considered because of the practical and economic difficulties of assembling the desired equipment under the proper conditions.

In an effort to alleviate this situation, we describe here a chip transport model or simulator that will allow a logger to realistically and economically determine the best way to get his daily trucking job done. Two examples illustrate the use of this model. Although designed for problems unique to chip trucking, the simulator can be used for almost any sort of wood trucking system.

THE ADVANTAGES OF SIMULATION

This simulator is a computer program that dynamically models all the essential actions and reactions of real chip transport systems. Everyone is familiar with model bridges and airplanes and their advantages in developing efficient and practical real structures. Our simulator is a model in the same sense but is concerned with the "structure" of men, equipment, and work rules.

As with any model, its main advantage is its ability to predict how a similar configuration of the real system will perform. But chip transport system simulation has several other related advantages.

First, the incredible speed of computers allows us to compress months of simulated activity into a few minutes of real time, and many different system alternatives and configurations can be examined in a fraction of the time and cost of one real experiment.

Second, simulation is flexible: the kinds of systems modeled are limited only by the user's imagination. In contrast to a bridge, which once designed and built will not be changed, a chip transport system must be able to respond to external changes in order to stay profitable. Thus, the simulator should be used each time some significant factor changes. These factors may range from distance to market to the availability of more economical trucks and trailers.

Third, the simulator allows a user to visualize the interactions of entire systems. For example, the time that one operation or piece of equipment must wait for another often suggests what changes to make. But the principal criterion for identifying system improvements is cost. Because the simulator constructs a cost record for each process and piece of equipment, cost effective changes are easily seen.

The simulator cannot tell the logger what is best in one step. It predicts how the real system will perform under a specific set of conditions: conditions such as the number of trucks and vans available, truck and van costs per hour, driving time to the mill, truck starting times each morning, and the value of a van of chips. If the logger is not satisfied with predicted profits or production under the specified conditions and work rules, he can change those conditions under his control and run the simulator again and again.

In effect, this simulator is a crystal ball for discovering unsuspected opportunities. But achieving all the advantages of this powerful tool depends a great deal on its proper use. There are two major requirements. First, a user must become familiar with the model, because studying

the model can uncover things he didn't understand about his real system as well as make him aware of any model limitations. Obviously, the model is not the "real world" but the user should be satisfied that its limitations are acceptable. If not, the model should be changed to conform to his expectations.

Second, a user must test the simulator against his own experience. If the model correctly predicts system performance under known conditions, the user will feel more confident in adopting its recommendations under new, untried situations. Of course, some caution is necessary: several small changes from known conditions are safer than one large change. For example, one would have more confidence in the results predicted by adding one more van than in the results predicted by adding four more vans and two new trucks, unless the intermediate changes had also been tested.

THE CHIP TRANSPORT SIMULATOR

This simulator is written in GPSS, or General Purpose Simulation System, developed by IBM.¹ Originally limited to their equipment, it is now available on most medium and large computers.

Although any computer language requires some effort to learn and apply, this language is especially oriented toward the users. As a result, it is the most widely used simulation language today. No computer program can claim to fulfill all demands placed on it, but we have attempted to provide a great deal of flexibility. And the use of GPSS has made it intrinsically easy for any other user to modify the program to his own needs.

The program itself is available to any interested individual or organization and is documented. For copies, write to:

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¹International Business Machines, Inc. 1971. *General Purpose Simulation System V Users Manual*. SH20-0851. 422 p. White Plains, New York.

Our model has five interactive segments corresponding to the real system's division of activity: (1) a chipper, (2) trucks and vans, (3) setout trucks, (4) a mill yard, and (5) records.

The Chipper

This segment models the functions of a chipper, filling empty vans with chips, closing them, and moving the chip spout if necessary. A logger must provide the following information for this segment: (1) the time required to fill a van, (2) the time required to close a full van, (3) the time required to move the chip spout, and (4) the number of slots for empty vans in front of the chip spout.

Note that the time required to fill a chip van lumps all the felling, skidding, and chipping activities into what can be termed a "black box". That is, if we say that the chipper fills a van in 35 ± 10 minutes, we mean that van filling time can vary from 25 to 45 minutes due to unspecified variation in felling, skidding, and chipping rates. This time estimate says nothing about how this rate is achieved, just that it *is* achieved. This is not to say that felling and skidding are unimportant, but the purpose of this simulator is to find the *best combination of men, trucks, vans, and rules to optimize trucking activity for the observed chipping rate*.

The question of slots for vans under the chipper's spout is also important in this model. Some chippers have chip spouts that can be moved to fill more than one van without moving vans and thus have several "slots". Other chippers have only one "slot" and, once a van is filled must wait for it to be removed and another empty moved into place. This feature greatly affects the use of trucks, vans, and setout trucks and will be discussed in the trucking segment.

Trucks, Vans, and Setout Trucks

These two segments have the job of moving full vans from chipper to mill. The number of trucks, setout trucks, vans, and hauling distance are the major factors affecting productivity.

Three different trucking situations are identified in this model and are distinguished primarily on how setout trucks, if

used, interact with the highway trucks. In the first, a setout truck is never used; in the second, setout trucks are used only when necessary because the incoming highway trucks can do much of the handling; and in the third, setout trucks are used exclusively for van handling. In addition, the model distinguishes between chippers with only one slot in front of the spout and chippers with two or more slots.

The logger must provide the following information for the trucking segment:

- (1) number of trucks
- (2) truck cost per hour including labor
- (3) number of vans
- (4) van cost per day
- (5) number of setout trucks
- (6) setout truck cost per day
- (7) truck travel time, loaded and empty, to and from the mill
- (8) time required for a truck or setout truck to hook up to and unhook from a van
- (9) time required for a truck or setout truck to move between the empty van storage area, full van storage area, and slots at the chipper
- (10) For the setout truck when there are two or more slots:
 - a. The number of empty vans in slots which the chipper must have in reserve
 - b. The number of slots that can be occupied by full vans before they "get in the chipper's way"

The Mill Yard

This segment models all the activities at the mill yard that determine how much time the logger's own trucks spend there being weighed, unloaded, and waiting for these services because of the competition from other trucks arriving at the yard.

Although all these activities can be modeled in great detail, they are usually beyond the control of the logger. As a result, this segment is modeled similar to the chipper and lumps all activities into the time required to complete all mill yard activities and start on the return trip to the landing. The logger must specify this time.

The Record Segment

This segment starts and stops the other segments each day according to the

schedule provided by the user and prints a daily summary of each segment's activities. The following information must be provided by the user:

1. Time each segment starts work each day.
2. Time each segment quits for the day:
 - a. After achieving a production quota?
 - b. After a specific elapsed time?

How to Use the Simulator

Each user must provide all the above statistics for his conditions. Equipment and decision rules can be chosen for his existing operation or for any system he wishes to examine. Time data are a bit more complicated. At one extreme, he can make rough estimates based on his experiences; at the other, he can make elaborate time studies of each operation.

Rough estimates may give some feel for the sensitivity of the model to certain operations. For example, a proportionately large error in estimating the time to move the chip spout from one van to another would probably have little effect on overall model accuracy while a small proportionate error in estimating travel speed to the mill could be serious. So data collection effort should be allocated to those data requirements that are most critical.

With his set of data, the user can then "run" the model for a desired length of time or until a desired production quota is reached. At this point the report of how much was produced, at what cost, and other features describing machine utilization and interaction can be examined for clues on how to improve system performance.

Many kinds of chip trucking problems can be solved using this simulator: What is the best combination of trucks and vans? How many setout trucks should I buy? Should I lease or buy additional trucks and vans? Can I alter work schedules to increase production or reduce costs? Is there an optimum truck and van size? How are hauling costs affected by distance to market? What effect does distance to mill have on the number of trucks and vans needed? The following examples of the use of our model

should give some idea on how the whole process works.

EXAMPLE NUMBER 1--A CASE STUDY

A timber producer has a full-tree chipping operation that annually produces nearly 30,000 tons of aspen chips for a hardboard plant more than 3 hours driving time away. To deliver his quota of eight loads a day, he developed (without benefit of simulation) a system using four trucks and eight vans plus one setout truck at the landing. At 6 a.m. all trucks begin their first trip to the mill with vans filled the previous day. At 7 a.m. the chipper and setout truck begin to fill the remaining four vans to be hauled that afternoon. When these four have been filled, the chipper is idle about 2 hours until one of the first four vans returns from the mill. The first four vans are then filled for the next morning's haul.

Because the chip spout was not very flexible, the single full van had to be pulled away and an empty van positioned before chipping could resume. Thus, although the chipper filled a van in an average of 28 minutes, another 26 minutes were consumed by the setout truck in removing the full van and bringing another empty, a total of 54 minutes. Given a 9-hour workday, his system was operating very near capacity considering refueling, normal maintenance, and knife changing. Even if his production quota were raised by the mill, his operation could not have supplied much extra wood without major changes.

Although there were many possible changes the logger could have considered, such as designing a more flexible chip spout, working a longer day, or even adding another shift, he chose to see if he could reduce the setout truck's van handling time. A simple suggestion was to add another setout truck. With a second setout truck already waiting with an empty van, it could move in as soon as the first setout truck removed the full van.

Thus the problem we examined with the simulator was this: would the addition of another setout truck be a cost-effective way to increase production? To answer this question, the logger ran a time study of

his operation. The results of his study were as follows:

Record Segment

Chipper work day--Begin at 7 a.m. and work until eight vans are filled with chips.

Truck scheduling--All trucks begin at 6 a.m. from garage, travel to landing for first full van, complete two round trips and finish at garage for night.

Cost and value (dollars).

Trucks, including labor	21.00/hour
Vans, each	1.80/hour
Setout trucks, each	1.80/hour
Chipper, including labor	50.00/hour
Value of chips	250.00/van

Chipper Segment

minutes

Fill the van	28
Close the van	5

Trucking and Setout Truck Segments *minutes*

Travel time on landing from van	
storage to chipper or return	5
Back into the slot	7
Move out of the slot	3
Hook up to a van	10
Drop a van	7
Travel time on highway:	
Garage to landing--empty	47
Landing to mill--loaded	187
Mill to landing--empty	192
Mill to garage--empty	145

Mill Segment

Time spent in mill yard activity 54

Although we show only average times for simplicity's sake, the data varied as would be expected in any real operation. Our model includes this variation, an important feature of any simulation.

Using these time data, 2 weeks of operations were simulated: the first week with one setout truck, and the second week with two. Instead of changing the production quota, however, we simply compared the times for both weeks that would have been available for more chipping if the mill would have purchased the wood and if additional vans and trucks were acquired. The results were as follows:

	One setout truck	Two setout trucks
Chipper time per day-- all activities re- quired to fill eight vans	8.99 hr	8.92 hr
Chipper time per van:		
Filling vans	28.43 min	28.43 min
Waiting for another empty van	25.63 min	10.22 min
Total	54.06 min	38.65 min
Chipper time per day waiting for trucks to bring more empties	1.78 hr	3.77 hr
Additional production if chipper was used to fill vans	1.97 vans	5.85 vans
Net revenue per trip	\$ 25.52	\$ 22.76
Net revenue for eight trips	\$204.16	\$182.08
Net revenue if addi- tional vans were filled and hauled to market	\$254.43	\$315.23

The simulator demonstrated that even if more chips could be sold, the use of a single setout truck could allow daily revenue (excluding felling, skidding, and all other costs) to increase by only 25 percent. On the other hand, adding an inexpensive second setout truck would enable daily net revenue to increase by 54 percent. This happened because the second setout truck reduced the time that the chipper spent waiting for another empty van from 26 to 10 minutes. And this reduction in wasted time increased the time available for more chipping from 1.78 hours to 3.77 hours per day.

Although the net revenue per trip is less for the second week because of the second setout truck's cost, total profits could be larger.

Admittedly, this is a fairly simple problem and simulation may not even have been required. Yet this actual case allowed the logger to see how realistic simulation can be and he is now interested in trying simulation on the more complex aspects of his operations. (The Appendix contains the two summaries of cost and activity provided by the simulator for this example.)

EXAMPLE NUMBER 2--A HYPOTHETICAL CASE

A second example represents a general problem faced by all chip truckers: How

many trucks and vans do I need? This question can be answered easily by simulation but there are really two different answers depending on the size of the logger's market for chips. If he can sell all the chips he can produce, he will get one answer. But if he is limited to a quota, the best combination of trucks and vans will be different.

Our logger has a full-tree chipping operation located about 50 minutes from the mill. His chipper can fill a van in about 28 minutes and works a 10-hour day. But unlike our first example, there are three slots for vans in front of his movable chip spout. This means that the chipper may not have to wait for another empty van. If the single setout truck has already placed another empty van in an adjacent slot, only the chip spout has to be moved.

Incoming trucks first try to drop their empty vans in a slot at the chipper. If these are already occupied, they will drop the van at the storage area if there are full vans ready to haul to the mill. If not, they will stay attached to the van and wait for a slot to open. Other features of the operation such as costs, mill yard activity, and the operation of a single setout truck are similar to the first example.

This logger would like to know, given the current chipping rate and distance to the mill, how many trucks and vans should he use.

Using the information describing his operation, we used the simulator to operate the system for 20 different combinations of trucks and vans (table 1). Four items are displayed: (1) average number of trips per day, (2) gross revenue per day, (3) truck, van, setout truck, and chipper cost per day, and (4) net revenue per day (excludes felling and skidding costs).

To emphasize the point made earlier, how one looks at this information depends on the situation.

The Logger can Sell as Much as He Produces

In this case the logger is concerned with net revenue per day. As each van is added, both the chipper and trucks spend less time waiting. But like most good things, the improvement can only go so far.

Table 1.--*Simulated gross revenue, cost, and net revenue per day for several truck and van combinations (In dollars)*

Vans :		Trucks (number)							
(number):	4	:	5	:	6	:	7	:	8
	(14.5) ¹								
4	G	3,625							
	C	1,447							
	N	2,178							
	(15.5)	(17.40)							
5	G	3,888	4,350						
	C	1,465	1,665						
	N	2,422	2,685						
	(15.85)	(18.60)	(20.05)						
6	G	3,963	4,650	5,013					
	C	1,483	1,683	1,883					
	N	2,480	2,967	3,130					
	(15.90)	(19.05)	(21.75)						
7	G	3,975	4,763	5,438					
	C	1,501	1,701	1,901					
	N	2,474	3,062	3,537					
	(19.10)	(22.10)							
8	G	4,775	5,525						
	C	1,719	1,919						
	N	3,056	3,606						
	(22.10)	(24.25)							
9	G	5,525	6,063						
	C	1,937	2,112						
	N	3,588	3,951						
	(24.40)	(24.60)							
10	G	6,100	6,150						
	C	2,130	2,305						
	N	3,970	3,845						
	(24.50)	(24.45)							
11	G	6,125	6,113						
	C	2,148	2,323						
	N	3,971	3,790						
	(24.50)	(24.50)							
12	G	6,125	6,125						
	C	2,166	2,341						
	N	3,959	3,784						
	(24.40)								
13	G	6,100							
	C	2,359							
	N	3,741							

¹Number in parentheses = average number of trips per day;

G = gross revenue; C = cost; and N = net revenue.

For example, with five trucks, the addition of an eighth van doesn't help at all because the maximum productive potential of these five trucks in a 10-hour day was reached with seven vans. The eighth van merely increases costs.

However, the productive capacity of the chipper has not been achieved yet. Five trucks and 7 vans can only move 19 vans per day while the chipper could theoretically produce 24 (600 min/day ÷ 25 min/van). To reach this point, more trucks and vans must be added.

The best combination under these conditions is found at 7 trucks and 11 vans.

Net revenue is at a maximum because the productive capacity of both chipper and trucks has been reached.

The Logger is Limited to a Quota of 20 Trips per Day

It should be apparent that because gross revenue is now limited to \$5,000 (20 trips, \$250/trip), the logger must find that combination of trucks and vans that can reach this goal at minimum cost. Note also that in table 1, truck, van, setout truck, and chipper cost for each combination is fixed whether the equipment is used to its potential or not.

Therefore, the best combination under a quota is the cheapest combination that can meet or exceed the quota. In this case it is six trucks and six vans. No smaller number of trucks regardless of vans can make 20 trips per day and adding a seventh or eighth van or more trucks is futile because we are not interested in wasted

chipper time now, just minimum cost. Net revenue under this combination is \$3,117 and no other can achieve the quota and earn more.

This example, though simple, shows the ease with which production functions can be determined by simulation.

APPENDIX.--ACTUAL SIMULATOR REPORTS OF THE CHIP TRUCKING OPERATION USED IN THE EXAMPLE

One Setout Truck

System Characteristics

Chipping

Chipper cost per hour including labor:
\$49.80

Number of slots: 1

Daily quota of vans to fill and haul
to mill: 8

Estimated average time to fill a van
with no waiting for wood (minutes):
28

Trucking

Number of trucks: 4

Number of vans: 9

Truck cost per hour including labor
(each): \$21.00

Van cost per hour (each): \$1.80

Van capacity (tons): 25

Value of a van delivered to the mill:
\$250.00

Estimated average time to haul a van
from landing to mill (minutes): 187

Setout trucks

Number of setout trucks: 1

Setout truck cost per hour: \$1.80

Setout truck operating rules:

- Setout truck will move an empty van to the chipper when more than 0 slots are open.
- Setout truck will move a full van to the storage area when less than 0 slots are open.

Production and cost statistics

General

Total days simulated: 5

Total trips completed to mill: 40

Average number of trips completed per
day: 8

Total revenue earned (all trips):
\$10,000.00

Total cost incurred (all trips):
\$8,978.96

Net revenue (all trips): \$1,021.04

Gross revenue per trip: \$250.00

Total cost per trip: \$224.47

Attributable to:

Chipper: \$55.96

Trucks: \$146.01

Vans: \$20.25

Setout trucks: \$2.25

Net revenue per trip: \$25.53

Chipper activity

Average chipper time per day--all
activities (hours): 8.99

Average time per day spent waiting for
vans to fill (hours): 5.00

Trucking activity

Average trucking time per day--all
activities (hours): 13.90

Average round trip time--all acti-
vities (minutes): 417

Productive time per trip: 406

Nonproductive time per trip waiting
for: 11

A slot to open: .00

Its own attached van to be filled:
.00

Its reserved full van to get to
the storage area: .00

Its turn to be weighed full or
empty: 2.00

Its turn to be dumped: 9.00

Setout truck activity

Average number of empty vans brought
to the chipper: 5.20

Average number of full vans brought
to the storage area per day: 8.00

Average time per day spent in an idle
status (hours): 1.81

Two Setout Trucks

System characteristics

Chipping

Chipper cost per hour including labor:
\$49.80

Number of slots: 1
Daily quota of vans to fill and haul
to mill: 8
Estimated average time to fill a van
with no waiting for wood (minutes):
28

Trucking

Number of trucks: 4
Number of vans: 9
Truck cost per hour including labor
(each): \$21.00
Van cost per hour (each): \$1.80
Van capacity (tons): 25
Value of a van delivered to the mill:
\$250.00
Estimated average time to haul a van
from landing to mill (minutes): 187

Setout trucks

Number of setout trucks: 2
Setout truck cost per hour: \$1.80
Setout truck operating rules:
Setout truck will move an empty van
to the chipper when more than 0
slots are open.
Setout truck will move a full van to
the storage area when less than 0
slots are open.

Production and cost statistics

General

Total days simulated: 5
Total trips completed to mill: 40
Average number of trips completed per
day: 8
Total revenue earned (all trips):
\$10,000.00
Total cost incurred (all trips):
\$9,089.55

Net revenue (all trips): \$910.45
Gross revenue per trip: \$250.00
Total cost per trip: \$227.23

Attributable to:

Chipper: \$55.50
Trucks: \$146.98
Vans: \$20.25
Setout trucks: \$4.50
Net revenue per trip: \$22.77

Chipper activity

Average chipper time per day--all
activities (hours): 8.92
Average time per day spent waiting
for vans to fill (hours): 5.00

Trucking activity

Average trucking time per day--all
activities (hours): 13.90
Average round trip time--all activi-
ties (minutes): 419
Productive time per trip: 407
Nonproductive time per trip waiting
for: 12
A slot to open up: .00
Its own attached van to be filled:
.00
Its reserved full van to get to
the storage area: .00
Its turn to be weighed full or
empty: .00
Its turn to be dumped: 12.00

Setout truck activity

Average number of empty vans brought
to the chipper per day: 6.20
Average number of full vans brought
to the storage area per day: 8
Average time per day spent in an idle
status (hours): 7.92

Bradley, Dennis P., and Sharon A. Winsauer.

1976. Solving wood chip transport problems with computer simulation. USDA For. Serv. Res. Pap. NC-138, 8 p. North Cent. For. Exp. Stn., St. Paul, Minn.

Efficient chip transport operations are difficult to achieve due to frequent and often unpredictable changes in distance to market, chipping rate, time spent at the mill, and equipment costs. This paper describes a computer simulation model that allows a logger to design an efficient transport system in response to these changing factors.

OXFORD: 825.71:781.1:U681.3. KEY WORDS: chipping, trucking, optimization.

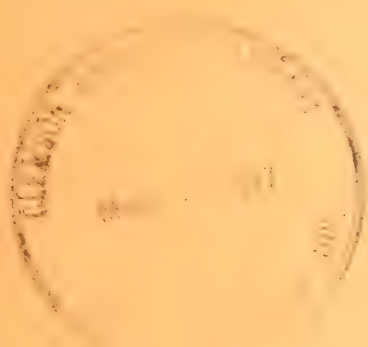
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DEPOSITORY ITEM

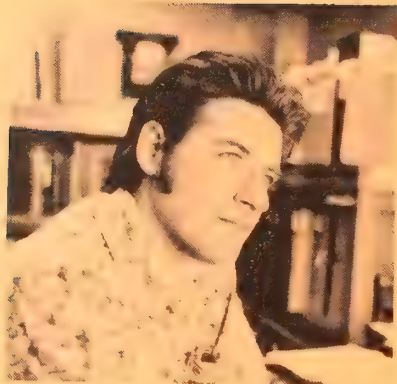
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influence on
soil properties
of prescribed
burning
under mature
red pine

DAVID H. ALBAN





THE AUTHOR

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INFLUENCE ON SOIL PROPERTIES OF PRESCRIBED BURNING UNDER MATURE RED PINE

David H. Alban

Mature red pine (*Pinus resinosa* Ait.) stands usually have a thick accumulation of organic matter on the soil surface and a dense shrub layer. These conditions hinder reproduction. Before the advent of the white man in North America, most red pine stands regenerated following wild-fires. The fires reduced shrub vegetation and improved seedbeds by reducing the depth of the forest floors.

Prescribed burning, therefore, is being studied as a potentially useful tool for establishing red pine stands. In Ontario, two consecutive summer burns practically eliminated hazel understory in 80-year-old red pine and white pine (*P. strobus* L.) stands. This produced good regeneration and increased survival of seedlings during the first year (Van Wagner 1963). Similarly, light intensity burns proved effective for understory control in loblolly pine (*P. taeda* L.) stands in southeastern United States (Lott et al. 1960): reproduction was improved and the growth of overstory trees wasn't affected.

The effects of fire on both soils and vegetation have been rather completely reviewed by Burns (1952) and Ahlgren and Ahlgren (1960). Although it is apparent that these changes are complex and depend on a host of factors, certain generalizations seem reasonably consistent: burning has its most pronounced effect on the forest floor in which carbon (C), nitrogen (N), and sulfur (S) are volatilized, and calcium (Ca), magnesium (Mg), potassium (K), phosphorus (P), and other elements are left as ash. This ash is leached by rains into the mineral soil which increases its base saturation and pH. These changes also may have important effects on the microbial population of the soil (Neal et al. 1965). Such soil changes are most pronounced during the first year after burns, but these properties usually revert to their preburn level within a few years. Infiltration rate also frequently decreases when soil pores are filled with fine material and soil animals are killed, which accelerates erosion under some topographic and climatic conditions.

In 1960, we initiated burning experiments to control beaked hazel (*Corylus cornuta*, Marsh) understory in a 90-year-old red pine (*Pinus resinosa* Ait.) stand in Minnesota. Twenty-eight treatment plots were installed; all of which had been thinned to 120 ft² of basal area per acre. Four plots were left unburned: the remaining 24 were burned either during the dormant season (spring) or the growing season (summer) at different intervals: annually, biennially, or periodically (6 to 9 years). Each treatment was replicated four times and assigned to the plots using a randomized block design.

Most burns were made between 5 to 15 days after a rain when the moisture content of the forest floor averaged 100 percent (spring) and 40 percent (summer). Backing fires from downwind were used to burn the first 20 foot strip. Headfires, which varied in width from 10 to 20 feet (fig. 1), were used to burn the remainder



Figure 1.--Ignition of second burn on a biennial plot.

of each plot. This minimized charring of stems, scorching of crowns, and kept forest floor weight losses to 50 percent or less.

Burning each treatment during its scheduled year was felt to be more important than getting the hottest possible fire. Prolonged dry periods with their potential for very hot fires were rare and burning only when they occurred would have resulted in very few burns.

The soils have been tentatively classified as belonging to the Cutfoot Soil series (deep, well-drained soils formed from medium and coarse sands that show only weak profile development). The forest floor prior to burning was about 3 inches thick, underlain by loamy sand A1, A2, and B2 horizons approximately 1/2, 4, and 14 inches thick, respectively. Below the B2 horizon, the

soils were mainly stratified sands and gravels interspersed with thin lenses of very fine sandy loam. Below 50 inches, calcium carbonate occurs sporadically (tables 1, 2, and 3).

By 1969, the overstory of the study stand was that of a nearly pure 100-year-old red pine stand (mean diameter at breast height, 14.7 in.; mean height, 76 ft; basal area, 141 ft²/acre; volume, 4,380 ft³/acre; site index, about 55 ft). Mortality from burning among the overstory trees was low: it totaled 3.5 ft² of basal area per acre, about half of which had been on the summer annual burn plots. The periodic annual volume increment of the overstory (average 93 ft³/acre) had not been significantly affected by the burns.

The understory on the unburned plots was dominated by hazel stems averaging 8-ft

Table 1.--Distribution of organic matter and nutrients in the forest floor on unburned plots

Horizon	pH	Ash	Ovendry weight	Organic matter	N	P	K	Ca	Mg
Percent			Lb/acre						
L	4.70	6.5	3,810	3,560	40	3.2	14.0	37	4.3
F	4.92	17.7	9,190	7,560	115	8.0	12.3	102	10.2
H	5.02	52.8	26,070	12,300	240	17.8	31.0	201	28.0
Total			39,070	23,420	395	29.0	57.3	340	42.5

Table 2.--Character of mineral soil on unburned plots

Depth (in.)	Bulk density	Gravel	Percent of <2mm soil			pH	N	P	Ca	Mg	K	H + Al
	g/cm ³		Clay	Silt	Sand							
			Percent				Percent					
							meq/100g					
0 to 4	1.24	0	5.0	12.3	82.7	5.32	0.059	0.017	1.98	0.40	0.17	0.60
4 to 20	1.41	6.1	4.9	5.8	89.3	5.65	.017	.029	.88	.24	.07	.52
20 to 39	1.48	10.7	4.3	1.1	94.6	5.75	.008	.024	1.63	.44	.09	.12

¹Estimated from measurements made on similar soils in nearby areas and assumed to be the same on burned and unburned areas.

Table 3.--Understory nutrient composition and weights on unburned plots¹

Nutrient	Herbs		Shrub leaves		Shrub stems		Total weight
	Percent	Lb/acre	Percent	Lb/acre	Percent	Lb/acre	
N	1.85	4.4	1.64	3.8	0.44	5.6	13.8
P	.25	.6	.24	.6	.06	.8	2.0
K	3.00	7.2	1.14	2.7	.25	3.2	13.1
Ca	.73	1.7	2.28	5.3	.80	10.2	17.2
Mg	.22	.5	.34	.8	.06	.8	2.1
Ovendry weight		239		233		1,279	1,751

¹An estimate of herbaceous vegetation was obtained in the summer of 1974 by clipping all herbaceous material on 25 subplots (2.7 ft²) on control plots.

in height. On the burned plots, most of the aboveground parts of the hazel plants had been killed. The summer burns, however, proved more effective in reducing hazel sprouting than did the spring burns. The mean number of hazel stems by frequency of burns are shown in the following tabulation:

<i>No. of Stems (M/acre)</i>	
Unburned (control)	17 (4) ¹
Summer burned	
Annual	0 (0)
Biennial	4 (1)
Periodic	42 (8)
Spring burned	
Annual	38 (10)
Biennial	54 (17)
Periodic	59 (8)

Clearly the summer annual and biennial burns were effective in reducing hazel whereas the other burns were not. Although the 10 summer annual burns had eliminated the hazel, Buckman (1964) concluded that a single burn, if hot enough, would have accomplished the same result.

Visual observations on the annual summer burned plots in 1974 showed that very few hazel plants were growing indicating that hazel reinvades slowly after it has been eliminated.

In the fall of 1969, soil samples were collected from four soil pits on each plot at depths of 0 to 4, 4 to 20, and 20 to 39 inches. These were composited in the field, air-dried at room temperature, and sieved through a 2-mm screen. The fine fraction was used for all laboratory analysis and a correction was applied for the coarse materials.

The mineral soils were analyzed for particle size distribution by hydrometer and sieving (Day 1965), for nitrogen using the Kjeldahl method (Bremner 1965), and for hydrogen and aluminum using titration with NaOH after extraction with KCl (Yuan 1959). Calcium, magnesium, and potassium were extracted using 1*N* neutral ammonium acetate and determined by atomic absorption. Phosphorus was extracted using 0.01*N* HCl (Alban 1972) and determined colorimetrically. pH was determined in a 1:1 soil/water mixture. Cation exchange capacity (CEC) was taken as the sum of the bases plus H and Al.

¹Standard error of the mean shown in parentheses.

Bulk density was assumed to be unaffected by burning (Lunt 1951, Metz *et al.* 1961). Therefore, only estimates for bulk density were made for each of the three depths based on measurements taken on sandy plots scattered throughout the Chippewa National Forest.

Forest floor samples were collected from 1-ft square areas on each plot by L, F, and H horizons. Forest floor oven-dry weights were determined at 70°C.

Three representative hazel plants collected from each of the control plots (12 plants) constituted the shrub sample.

The shrub samples were oven-dried at 70°C, after which the leaves were separated from the stems and the ratio of leaf to stem weight was determined. This ratio was used to estimate pounds per acre of the leaves and stems based on hazel volumes measured in 1969 and stem densities, which had been measured previously (Buckman 1966).

Samples of the forest floor and the understory plants were ground in a Wiley mill to pass a 20-mesh screen and redried at 70°C before nutrient analysis. The concentration of each nutrient in the forest floor and in the understory plants was determined as follows: N by Kjeldahl; and Ca, Mg, K, and P by ashing in a muffle furnace at 525°C for 2 hr followed by uptake in 3*N* HCl, and determination as for the mineral soils. An estimate of organic matter was made from the loss on ignition at 525°C. pH was determined using a 4:1 water/organic material ratio.

RESULTS AND DISCUSSION

Burning destroyed the L horizons on all plots and the F horizons on the annual and biennial burned plots. On the periodically burned plots, the F horizon was reduced but not eliminated. The color of the H horizons turned black because of charring and the downward movement of organic colloids. This horizon was compacted; and presumably it became less porous. Except for occasional darkening near the surface, changes in the mineral soil were not discernible.

The summer annual burns consumed all of the forest floor and exposed the mineral soil in patches covering less than 5 percent of the area of the burned plots. This

agrees with Tarrant (1956), who reported that slash burning exposed mineral soil on less than 3 percent of the burned area in the Douglas fir region. However, studies involving more intense fires have been reported in which the mineral soil was left exposed on 25 to 50 percent of the study area (Van Wagner 1972).

Forest Floor

The organic matter in the forest floor was reduced by nearly one-half by the annual summer burns (table 4). This amounted to about 11,000 lb/acre, which corresponds with the amount of organic matter in the L and F horizons of the unburned plots (table 1). Thus, it appears the H horizon remains unburned even under the most intense burning, except in isolated patches where large amounts of fuel have accumulated.

Annual accumulation of litter to the forest floor can be roughly estimated as equal to the weight of the forest floor L horizon--about 3,810 lb/acre (table 1). This agrees with litterfall estimates for red pine reported by Chandler (1944), Lunt (1951), and Tappeiner and Alm (1975). However, it is about 50 percent greater than values reported by Alway and Zon (1930) and about 35 percent lower than those obtained under a 40-year-old red pine plantation on a sandy soil in northern Minnesota. It also agrees very closely with estimates published by Bray and Gorham (1964) for stands at latitudes comparable to Minnesota.

Shrub leaves contributed 233 lb to this estimate of 3,810 lb/acre; herbs, 239 lb (table 3). Thus, together they only accounted for approximately 12 percent of the total, which is comparable to the 15

percent reported by Scott (1955) for stands in Connecticut.

The contribution of the understory to the nutrient content found in the litter, however, is much greater than this 12 percent would indicate because of the high nutrient concentration in understory foliage. For example, the understory nutrient concentrations shown in table 3 are 1.5 to 5 times higher than those reported for overstory red pine trees by Hoyle and Mader (1964), Alban (1974), or Tappeiner and Alm (1975). Moreover, they are similarly higher than those found in the L horizon of the unburned plots, which were composed primarily of red pine foliage.

The same amounts of organic matter were left on the ground on all the summer burned plots after fire, regardless of frequency of burns. This can be derived by subtracting the amount of litter which has fallen onto the plots since the last fire from the total forest floor weight (table 4): for the summer biennial burns, subtract 1 years' litterfall (3,560 lb--table 1), and for the summer periodic burn, subtract 2 years' litterfall (7,120 lb).

The weight of the organic matter in the forest floor of the summer periodically burned plots averaged only 2,900 lb/acre less than the average for the unburned plots (table 4). This indicates that the organic matter in the forest floor returns rapidly to preburn levels.

Because all the spring burns were burned in 1969, the values of organic matter shown in table 4 are directly comparable. The slight decreases from annual to biennial to the periodic treatments probably can be attributed to more litter accumulating on the less frequently burned

Table 4.--Effect of burning on the forest floor

Treatment	pH	Organic matter	N	P	K	Ca	Mg	Months since last prescribed fire
Lb/acre								
Control	4.91	23,400	395	29.0	57.3	340	42.5	--
Summer								
Annual	5.95*	12,400*	265*	21.8*	33.5*	289	33.0*	2
Biennial	5.72*	14,900*	287*	21.0*	40.2*	315	34.8*	14
Periodic	5.30*	20,500	343	22.9*	39.3*	323	35.6	26
Spring								
Annual	5.88*	18,600*	346	27.0	53.1	403	45.5	4
Biennial	6.00*	17,500*	348	28.2	70.2	438*	48.7	4
Periodic	5.86*	15,700*	298*	23.5*	55.0	322	36.5	4

*Indicates significant differences from the control at the 10 percent level.

s, and that these caused hotter burns than those on the more frequently burned plots.

Nutrient and pH Changes

Lower amounts of N, P, K, Ca, and Mg were found in the forest floor on the annual summer burn plots than were found on unburned plots (table 4). However, the reduction in the amount of K was pronounced as the reduction in organic matter. This indicates that some of the nutrients released during burning are retained, at least temporarily, within the burning forest floor, which increases the concentration of bases in the forest floor, as well as the volatilization of organic acids during burning increased the pH from 4.91 to 5.95.

After the annual summer burns most of the released Ca, much of the released Mg, and little, if any, of the released K is retained within the forest floor (table 4). The strength with which cations are held to exchange sites decreases in the order $Ca > Mg > K$ (Black 1968, p. 237). Thus, the Ca released during burning is selectively absorbed into the exchange sites. The reduction in nitrogen in the forest floor is due to volatilization (Knight 1969) and possibly also to downward migration of organic material (DeBano *et al.* 1969).

After summer annual burning phosphorus is reduced in the forest floor. P is released after burning as a negatively charged ion; therefore, it would not be expected to be held on the exchange sites of the forest floor because most of the sites are negatively charged. Most P in forest soils is held as iron and aluminum precipitates (Wild 1950). Therefore, P released after fire should be most strongly retained within the mineral soil where iron and aluminum are concentrated.

The biennial and periodic summer burns affected the forest floor in much the same way as the annual burns except that the effect has been lessened somewhat by the litterfall on these plots since the last burn (table 4). The composition of the litterfall since the last burns on the annually and periodically burn plots is probably similar to that in the L horizon of the unburned plots (table 1). It has decreased the organic matter and nutrients and lowered the pH of the forest floor on the biennially and periodically burned plots.

The spring periodic treatment was burned in 1960 and 1969. Thus, by 1969 the L and F horizons and the shrub layer had built essentially back to their pre-burn level (Buckman 1964). Consequently, the 1969 fire would have consumed about 7,700 lb/acre of forest floor organic material (table 4) as well as about 1,279 lb/acre of shrub stems (control level table 3) consisting primarily of hazel, but with some willow, serviceberry, etc. Obviously with this amount of organic material consumed, there would be a large loss of nitrogen, and a sizeable deposition of nutrient-rich ash on the forest floor. This large deposition of nutrients has largely been leached from the forest floor as shown by the fact the P, K, Ca, and Mg actually are slightly lower on the spring periodic plots than on the control (table 4).

The annual and biennial spring burns substantially reduced the organic matter of the forest floor and increased its pH. The amounts of most nutrients are not significantly different from those on the unburned plots, but the trends indicate slight decreases of N and P, and increases of Ca and Mg.

Only on the annual and biennially spring burned plots was there evidence of nutrient accumulations in the forest floor. This can probably be attributed to the vigorous growth of the herbaceous vegetation on these plots. In 1969, for example, the litter accumulations (L horizon) on the following were (lb/acre): spring annual burn plots, 4,530; spring biennial, 4,860; spring periodic, 3,160; and summer annual, 3,840. The greater litterfall on the spring annual and biennial burned plots is also considerably richer in nutrients than other plots due to the higher percentage of herbs (table 3). This indicates a greater degree of nutrient cycling occurred as a result of these burns.

Mineral Soil

The clay content was not significantly affected at any depth by the burns (table 5). Soil pH in the 0 to 4 inch layer was significantly increased after all except the summer periodic burns. Below 4 inches, there were no significant changes in pH.

Cation exchange capacity (CEC) was higher after burning in the 0 to 4 and

Table 5.--Effect of burning on the mineral soil

Depth (in.)	Treatment	Clay Percent	CEC meq/100g	pH	N	P	K	Ca	Mg
----- Lb/acre -----									
0 to 4	Control	5.0	3.15	5.32	654	186	75.1	438	54.3
	Summer (annual and biennial) ¹	4.4	3.17	5.53*	620	260*	69.6	471	58.7
	Summer (periodic)	4.3	3.36	5.44	663	226	67.8	496	65.1*
	Spring (all burns) ¹	5.4	3.65*	5.50*	683	252*	82.2	561*	67.2*
4 to 20	Control	4.9	1.71	5.65	784	1,260	135	827	140
	Summer (annual and biennial) ¹	4.2	2.15	5.71	852	1,210	174	1,260*	196
	Summer (periodic)	4.7	2.16	5.65	880	939	170	1,190	194
	Spring (all burns) ¹	5.0	2.57*	5.66	918	1,160	200*	1,520*	250*
20 to 39	Control	4.3	2.28	5.75	449	1,400	203	1,930	323
	Summer (annual and biennial) ¹	4.2	2.86*	5.84	492	1,540	207	2,460*	377*
	Summer (periodic)	5.0	2.17	5.82	508	1,230	181	1,900	320
	Spring (all burns) ¹	3.9	2.31	5.77	448	1,370	184	1,950	302

*Indicates significant differences from the control of the 10 percent level.

¹Effects didn't differ significantly; therefore, these are combined.

particularly the 4 to 20 inch layers, even though only the effects of the spring burns were significantly different than those on the unburned plots. The summer annual and biennial burns increased cation exchange capacity in the 20 to 39 inch layer. The CEC of soils is largely a function of the kind and amount of clay and organic matter as well as of pH. The increases would require sizeable translocation of clay, which didn't occur. The pH changes do not seem adequate, particularly in the deeper layers, to explain the CEC changes either, although they might have played a minor role. It would seem that the downward translocation of organic material, as hinted at by the nitrogen increases, must be largely responsible for the increases CEC. Kononova (1961, p. 62) and Black (1968, p. 222) have reported that soil organic matter has a CEC measured in the hundreds of meq/100 g, and that the values increase as the pH rises. The very high CEC of the organic matter means that small amounts of organic matter when translocated downward in the profile of soils having low CEC can significantly increase the soil CEC.

An increase in CEC improves the capacity of the soil to hold cations. It is obvious in table 5 that Ca and Mg (the predominant cations on the exchange sites) have increased wherever the CEC has increased. It's noteworthy that all spring and the summer periodic burns produced the largest increases of Ca and Mg in the 4 to 20 inch layer but none in the 20 to 39 inch layer. The summer annual and biennial

burns, however, produced large cation increases in both of these layers. This indicates that downward leaching of Ca and Mg was the most intensive after the summer annual and biennial burns. This would be expected because these burns would reduce more than other burns the amounts of understory vegetation available to intercept rainfall and the amount of forest floor to absorb and retain rainfall.

Soil nitrogen was not significantly altered by burning but the tendency was for slight increases in the 4 to 20 and 20 to 39 inch layers. This may represent the downward movement of organic material after burning that was observed by DeBano *et al.* (1967) and Smith (1970).

The phosphorus in the 0 to 4 inch layer increased considerably after burns, which reflects the limited mobility of phosphorus in acid soils. This concurs with Wild (1950) who reported that phosphorus is strongly retained by acid soils and with Cole and Gessel (1965) who showed that very little P moves below 36 inches in a gravelly soil even after clearcutting.

The effects of burning on the soil (tables 4 and 5) are the combined result of the most recent burn and the burning regime over the last 10 years. An indication of the importance of the last burn can be obtained from the data for the dormant season burns, all of which were burned in 1969. Both the forest floor and the mineral soils differed little among the three treatments even though the spring annual

s were burned 10 times whereas the
ng periodic burns were burned only
e. Data from a similar study in South
lina showed that prescribed burning
10 years affected some soil properties
that continued burning for another 10
s resulted in little further soil
ges Wells (1971).

CONCLUSIONS

Even though burning has reduced the
nt of organic matter and nutrients in
forest floor, these losses are more
made up for by increases within the
ral soil. These soil changes and the
fected tree growth suggest that pre-
bed fires resulting in volatilization
p to one half of the forest floor
ht have had no affect on site
uctivity.

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OXFORD: 435.2:231.322:114.2. KEY WORDS: *Corylus cornuta*, forest floor, soil nutrients, understory, N, P, K, Ca, Mg.

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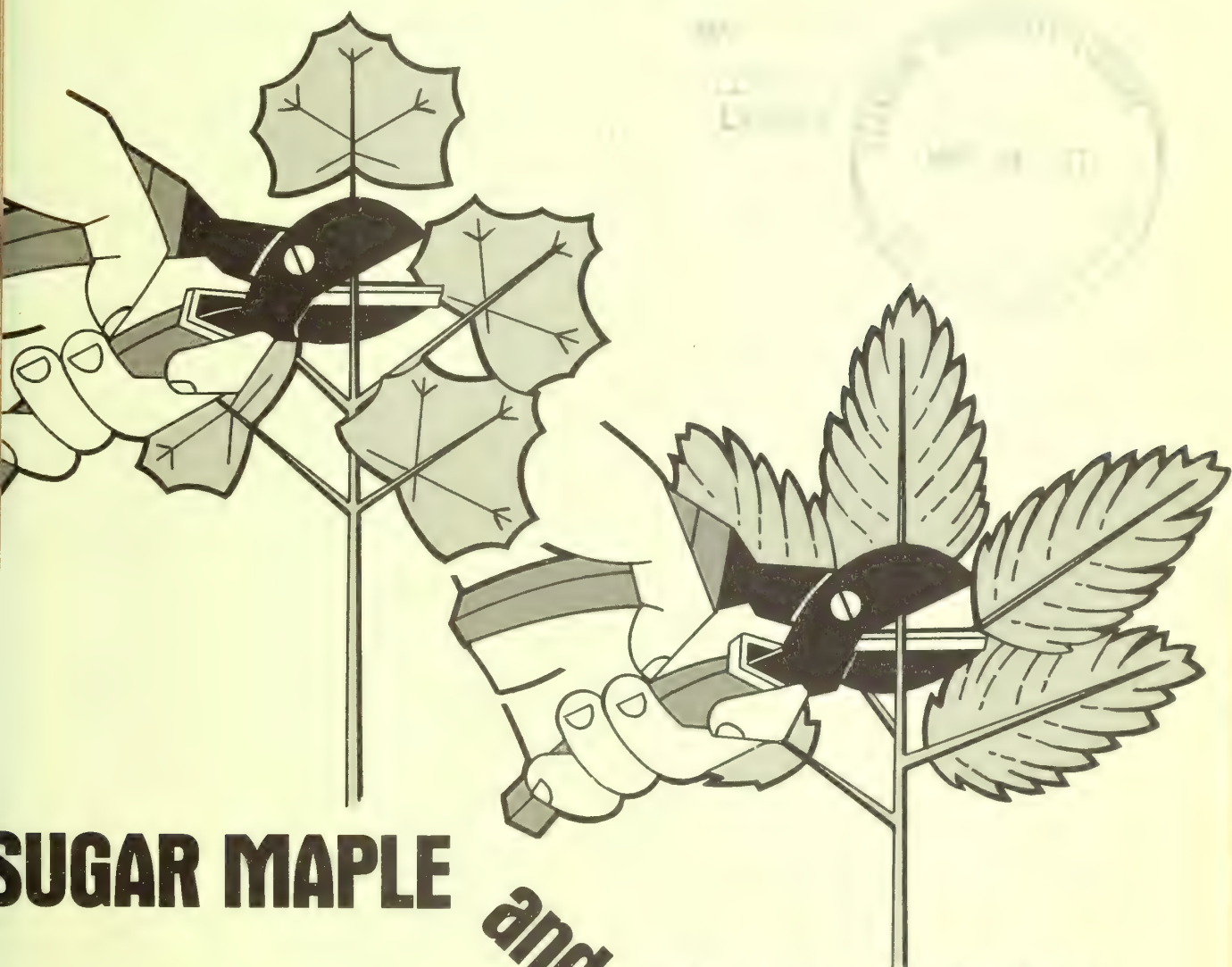
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Put trash in the proper place.



SUGAR MAPLE *and* **YELLOW BIRCH**
SEEDLING GROWTH after
SIMULATED BROWSING

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SUGAR MAPLE AND YELLOW BIRCH SEEDLING GROWTH AFTER SIMULATED BROWSING

Frederick T. Metzger

Many shoots and buds of northern hardwood reproduction are damaged by insects (Knight 1968) and browsing animals (Stearns 1968). Such damage to the terminal shoot has long been considered detrimental to height growth, stem form, and vigor.

Jacobs (1969) found deer browsing does not always hamper sugar maple seedling development. His results prompted a study of how growth of damaged seedlings is influenced by seedling characteristics and leader injury during the dormant season.

Sugar maple (*Acer saccharum* Marsh) and yellow birch (*Betula alleghaniensis* Britton) seedlings were used and represent two broad groups of trees that differ in shoot organization. Sugar maple's winter buds contain preformed shoots; they have true terminal buds and the lateral buds are opposite. Shoots in the winter buds of yellow birch are not fully preformed (Kozlowski and Clausen 1966) and apical buds may abort; lateral buds are alternate.

METHODS

The study was conducted in two stands of sugar maple-beech-yellow birch (SAF type 25) on the Upper Peninsula Experimental Forest near Marquette, Michigan. The sugar maple seedlings were under a shelterwood overstory cut to 97 ft² of basal area per acre (22 m²/ha) and treated with herbicides in 1960 and recut to 80 ft² (18 m²/ha) in 1966. The yellow birch seedlings grew in a clearcut area 2 chains (40 m) by 8 chains (160 m) cut and treated with herbicides in 1960. Both stands were originally mature to overmature. No natural animal injury to leaders occurred during the study.

Under natural conditions the number and size of buds on leaders and the length of leaders vary greatly. A bud position index was devised to account for these differences and permit standardizing treatments. Values were derived by dividing the number of lateral bud positions on a leader

into the number of buds or bud pairs located above a selected bud (fig. 1). Buds with a given index value bear a relatively constant relation to the lengths of the other buds on the leader.

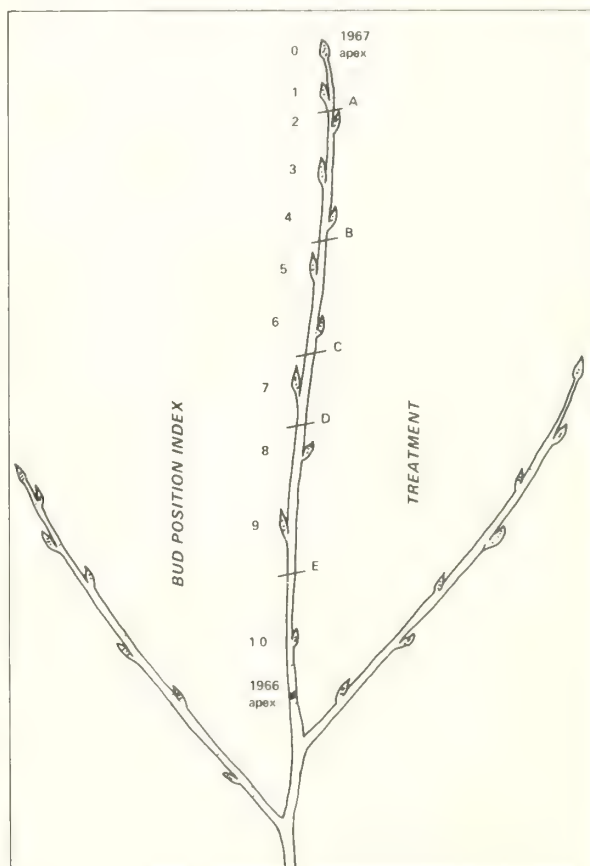


Figure 1.--Shoot of yellow birch illustrating treatment locations and bud position indices for an 11-bud leader.

Treatments simulated natural damage by removing portions of the current-year leader above specific bud position indices (fig. 1). Bud position and size, and the amount of leader removed by treatment is given in table 1. The 6 treatments were replicated 10 times, using a total of 60 seedlings of each species.

Table 1.--Summary of treatments: mean bud lengths, positions, and percent of leader and buds removed

YELLOW BIRCH						
Treatment	: Control :	A :	B :	C :	D :	E :
Bud length (mm)	5.4	² 6.4	7.6	² 6.3	5.8	2.2
Bud position ¹	0	0.15	0.41	0.66	0.84	0.95
Buds removed (percent)	0	14	37	61	77	87
Leader removed (percent)	0	13	35	63	85	97
SUGAR MAPLE						
Bud length (mm)	² 6.8	3.5	² 6.3	² 6.0	4.8	0.9
Bud position ¹	0	0.18	0.46	0.64	0.82	1.00
Buds removed (percent)	0	15	39	54	70	85
Leader removed (percent)	0	1	30	63	84	98

¹See text for definition.

²Bud length means that do not differ significantly at 0.05 level, Duncan's new multiple range test. All other bud length means differ from others within a species.

Elongation of all shoots developing in 1968 that originated from buds on the 1967 leader was measured weekly during the period of rapid growth and less often later in the season. The dominant shoot was determined at the last measurement in October.

The relation of a bud's length to its position on the leader was determined from measurements on 100 undisturbed seedlings of each species.

Treatments were arranged in a randomized block design. T-test, analysis of variance, and Duncan's new multiple range test with a 0.05 level of significance were used. Stepwise multiple regression procedures (UCLA-BMD02R programs) were used to screen tree characteristics related to shoot elongation. Final equations consisted of variables whose contribution to reducing the residual variance was significant at the 0.05 level.

RESULTS

Yellow Birch

Bud length as related to leader position on undamaged seedlings is described by a quadratic equation that accounts for 54 percent of the variation in length (fig. 2). Maximum lengths occur between bud position indices 0.33 to 0.50. The shortest buds are at the base of the leader. Eighty percent of all lateral buds are longer than the terminal.

On unclipped yellow birch, shoot elongation from terminal and lateral buds on

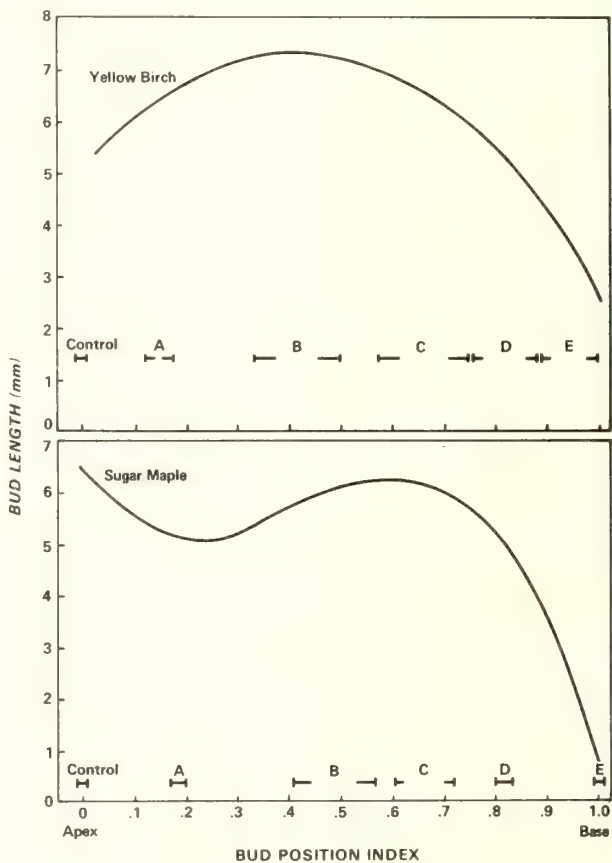


Figure 2.--Relation between bud length and position on 1967 leaders and range of positions included in clipping treatments. Regression equation for the relations are: yellow birch-- $BL = 5.12 + 11.01 BPI - 13.25 BPI^2$; Sugar maple-- $BL = 6.64 - 15.91 BPI + 48.86 BPI^2 - 38.83 BPI^3$; where BL is bud length and BPI is bud position index.

the leaders was related to bud length. The longest shoots originated from the longest buds; they were 60 percent longer than the leaders (fig. 3). After the 1968 growing season, these lateral shoots also projected above the leaders on 40 percent of the seedlings. Below a bud position index of 0.50, bud length became unimportant, as only short-shoots (less than 0.02 ft) developed. Short-shoots developed rapidly, ceasing elongation by late May. Long-shoot laterals and the leader continued elongation into August.

stimulated elongation in treatments C, D, and E. Buds that normally would have been short-shoots on unclipped seedlings elongated as much as normal leaders.

One season after clipping the heights of treatment A and B seedlings were comparable to the controls (0.05 level, table 2). The growth of replacement leaders in treatments C, D, and E was not stimulated enough to offset the loss of the old leader and their heights declined significantly.

The period of most rapid elongation was delayed in proportion to the severity of treatment. In seedlings with the severest clipping, peak growth rate was delayed 20 days.

Regression analyses showed that the extent of shoot elongation was dependent upon both bud and other seedling properties. Sixty-three percent of variation in shoot elongation was accounted for by height growth two seasons before clipping and the interaction terms of position of the bud originating the shoot and its length, total seedling height, and height growth during the second season before clipping. These variables were about equally important on the basis of standard partial correlation coefficients. Similar analyses of the change in height caused by clipping and regrowth gave a slightly more precise equation with fewer variables. Seedling height and bud length and position accounted for 66 percent of the variation in the change. Bud position and percent of stem removed could be interchanged in the equation without affecting its precision.

Sugar Maple

Bud-size patterns in sugar maple differed from yellow birch. Terminal buds were the longest bud on 69 percent of the leaders. When they weren't, only one pair of lateral buds usually exceeded them in length. The longest lateral buds occurred between positions 0.4 and 0.6. Buds immediately below the terminal bud were the shortest lateral buds in leaf axils. Buds at the base of the leader were even shorter (usually <0.5 mm) but these were associated with the bud scale scars of the prior year's terminal bud (Church and Godman 1966). Seventy-eight percent of the variation in bud length was accounted for by a cubic expression of bud position (fig. 2).

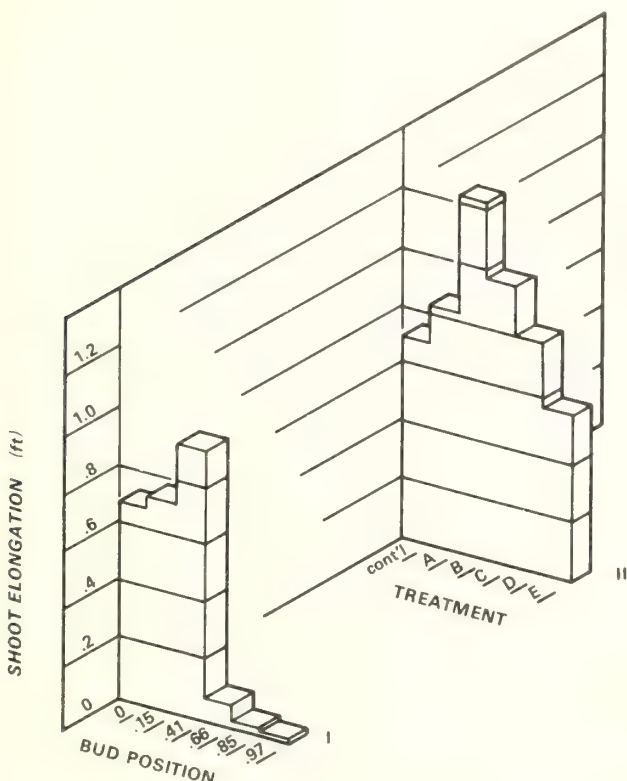


Figure 3.--Shoot elongation of yellow birch in relation to bud position and degree of clipping. (I) Normal pattern on unclipped seedlings for terminal and lateral buds in positions comparable to those in treatments. (II) Pattern for buds left uppermost on clipped seedlings and the leader of the control.

Clipping did not adversely affect elongation of replacement leaders (fig. 3). In all treatments, the replacements elongated as much as normal leaders on unclipped seedlings. Comparing shoots from buds at the same position on clipped and unclipped seedlings showed no differences in lengths for treatments A and B. However, clipping

Table 2.--Net height increment¹ following clipping
(In feet)

Species	Control	Treatment				
		A	B	C	D	E
Yellow birch	2.09 _a	0.96 _a	0.75 _a	0.33 _b	-0.34 _c	-0.56 _c
Sugar maple	.80 _a	.51 _b	.44 _b	.37 _b	.00 _c	-.42 _d

¹Net height increment = height one season after clipping - height before clipping.

²Common suffix indicates species means that do not differ significantly at the 0.05 level of rejection.

In contrast to yellow birch, leaders on unclipped sugar maple elongated twice as much as any lateral shoot (fig. 4). Most of the lateral shoots originated from the larger lateral buds at positions 0.3 to 0.5. On the balance of the leader, only one-third of the buds in leaf axils and none of the basal buds at position 1.0 broke dormancy. Leaders attained 90 percent of their elongation by mid-June. Lateral shoots did so more rapidly, reaching this level by early June.

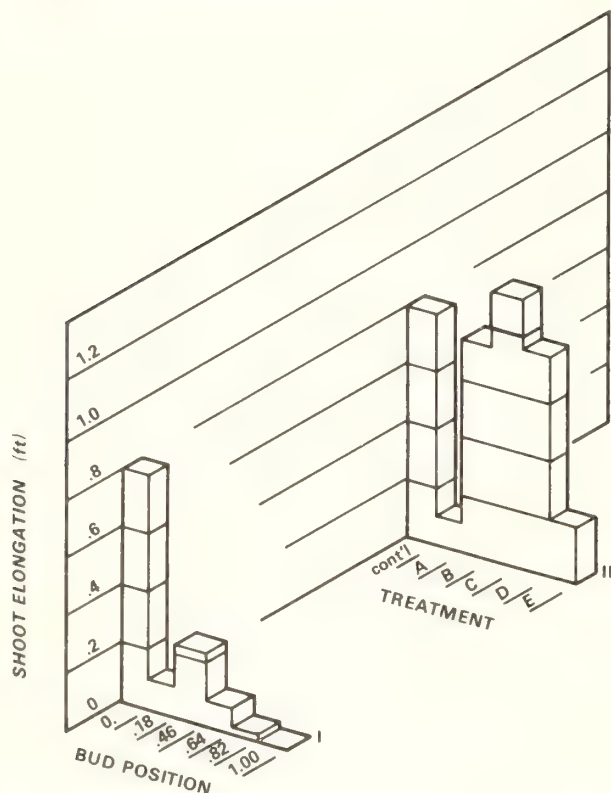


Figure 4.--Shoot elongation of sugar maple in relation to bud position and degree of clipping. (I) Normal pattern on unclipped seedlings for terminal and lateral buds in positions comparable to those in treatments. (II) Pattern for buds left uppermost on clipped seedlings and the leader of the control.

Clipping promoted elongation of the replacement leaders in treatments B, C, and D; they equalled normal leader growth on unclipped seedlings (fig. 4). The new leaders in treatments A and E were less than one-fourth the length of leaders of unclipped seedlings. Thus heights of all clipped seedlings were significantly less than unclipped maple at the end of season (table 2).

Damage to the terminal bud often results in forking, a serious defect in older trees. Consequently, lengths of bud pairs left uppermost after clipping and their shoot growth were compared. Fork members on clipped seedlings were comparable in length (± 10 percent) on 26 percent of the seedlings. Length of the bud pairs had to differ by more than 0.5 mm before the larger bud would consistently originate the dominant shoot, this difference only occurred in 28 percent of all bud pairs.

Seventy-five percent of the variation in shoot elongation was accounted for by the position of the bud from which the shoot originated and interaction terms of position, bud length, and leader growth in each of the two preceding seasons. The most useful variable in the equations was bud position. Similar analyses of the change in seedling height after clipping showed 70 percent of its variation was due to bud length, bud position, and leader growth the year prior to clipping. Here again, bud position and percent of stem removed could be interchanged without affecting precision of the equation.

DISCUSSION

This study demonstrates that the ability of sugar maple and yellow birch seedlings to recover from dormant season damage is more related to factors that determine growth rate than to the gross extent of damage. This helps explain the

less detailed observations of others; Tubbs (1969) and Godman and Krefting (1960) found yellow birch seedlings damaged by frost often grew better than undamaged seedlings. Jacobs (1969) found growth on repeatedly browsed sugar maple seedlings equalled protected seedling growth.

Several factors help minimize the effects of leader damage on growth of sugar maple and yellow birch. Lateral buds, which can replace a damaged or lost terminal bud, are well distributed along the leader. Their growth potential is determined by conditions occurring in the growing season prior to damage and is not seriously altered by damage. The critical period occurs while the embryonic shoot is developing in the bud in the first growing season. However, damage does alter the competitive position of the buds.

Species having preformed shoots within their buds illustrate how shoot elongation potential is determined during bud development. Owston (1969) found the embryonic shoot in white pine possessed primordia for all the leaves and internodes. Critchfield (1971) suggests that elongation of preformed leaders occurs by expansion of existing rather than by formation of new tissue at the time of elongation. In such species, elongation is completed early in the growing season; it depends on stored carbohydrates produced in the season preceding elongation (Olofinboba and Kozlowski 1973, Gordon and Larson 1970). Little (1970) indicates hormone synthesis is predetermined in the bud, is related to bud size, and regulates the flow of nutrients to the elongating shoot by mediating the production of auxin during elongation. Leader elongation, terminal bud length, and climate during bud development are all correlated, whereas the two growth parameters are not as well correlated to climate during shoot elongation (Kozlowski 1964, Hellum 1967, Clements 1970).

These previous studies involved leader elongation on undisturbed trees. The seedlings' response to clipping in this study suggests that the development of a replacement leader is also influenced by events of the prior season. A considerable proportion of the variation in growth was explained by seedling characteristics determined prior to damage. This was especially evident in sugar maple, which has preformed shoots in its buds (Critchfield 1971) and rapid early shoot elongation (Jacobs 1965).

Kozlowski and Clausen (1966) reported that yellow birch has heterophyllous shoots within its buds that elongate throughout the season; thus new tissue is added and currently produced photosynthates are used. Shoot elongation in yellow birch also is dependent upon factors occurring before damage but to a lesser degree than in sugar maple. In yellow birch this dependence may be due to a relation of bud parameters to the level of development of the embryonic shoot and its two large embryonic leaves. The size of these leaves when expanded appeared related to bud length and position. These leaves are essential to the survival and elongation of the shoots (Kozlowski and Clausen 1966).

Seedling environments in this study favored vigorous development. Less favorable environments would likely reduce the seedlings' ability to respond to damage. Sugar maple seedlings having short leaders also have shorter lateral buds in relation to the terminal. Thus under conditions unfavorable to growth, the seedlings would have fewer and less-developed lateral buds.

Growth characteristics of different plant species need to be understood before appraisals of damage or browse and timber production are accurate. Even the moderate degrees of clipping used in this study showed that growth response depended on bud characteristics, vigor, size, and species of the tree. Environmental factors such as moisture, light, and competition are also important to growth and influence the analysis of seedling injury.

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